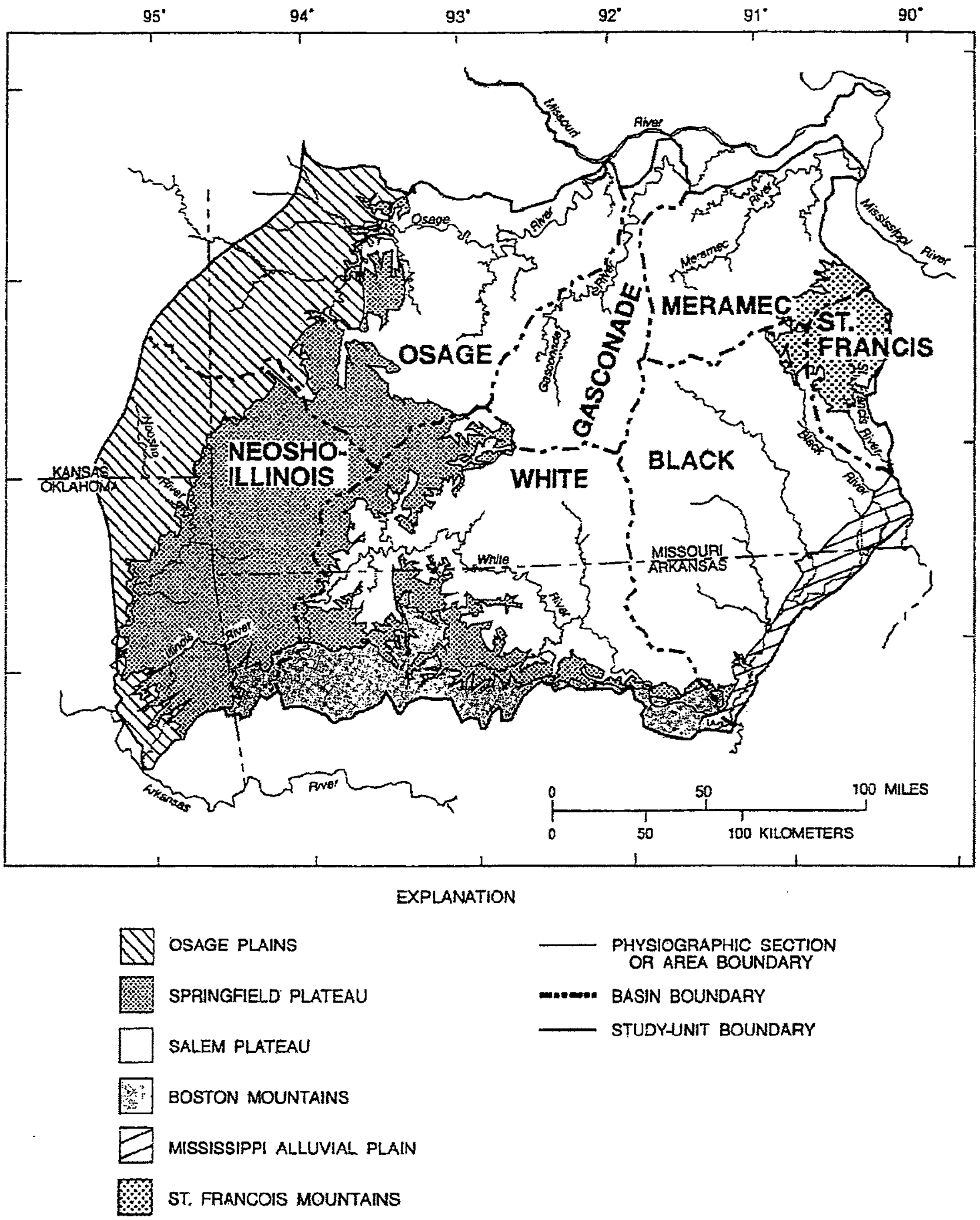

Figure 15. Major river basins and physiographic sections or areas in the Ozark Plateaus study unit.

Table 4. Summary of major tributaries, reservoirs, and land use in the major river basins in the Ozark Plateaus study unit

[Land use codes: F, forest; P, pasture; C, cropland; U, urban; M, mining; NA, not applicable]

River basin	Drainage area, in square miles		Land use, in order of importance	Principal tributaries and drainage areas, in square miles		Principal reservoirs in the river basin
	Total	Study unit				
White River[1]	27,800	11,300	F, P, C, U	War Eagle Creek	332	Beaver Reservoir
				Kings River	565	Table Rock Lake
				Crooked Creek	462	Lake Taneycomo
				Buffalo River	1,340	Bull Shoals Lake
				James River	1,460	Norfork Lake
				North Fork White River	1,830	
Neosho-Illinois Rivers[2]	14,100	9,230	C, P, F, M	Spring River	2,510	Lake O' the Cherokees
				Elk River	872	Lake Hudson
				Big Cabin Creek	450	Fort Gibson Lake
				Osage Creek	206	Tenkiller Ferry Lake
				Baron Fork	307	
Osage River[3]	15,300	10,500	C, P, F, M	Little Osage River	570	Truman Reservoir
				Marmaton River	1,150	Lake of the Ozarks
				South Grand River	2,040	Stockton Lake
				Sac River	1,970	Pomme de Terre Lake
				Pomme de Terre River	828	
				Niangua River	1,040	
Gasconade River[4]	3,600	3,600	F, P	Big Piney River	760	None
				Osage Fork	520	
				Roubidoux Creek	300	
				Little Piney Creek	272	
Meramec River[5]	3,980	3,980	F, P, M	Bourbeuse River	841	None
				Big River	964	
St. Francis River[6]	6,480	1,310	F, P, M	NA	NA	Lake Wappapello
Black River[7]	8,560	8,560	F, P, M	Current River	2,610	Clearwater Lake
				Spring River	1,230	
				Eleven Point River	1,220	
				Strawberry River	792	

[1] Does not include the Black River Basin, which is the largest tributary of the White River. Drainage area for James River from Homyk and Jeffery (1967); all other drainage areas from Sullavan (1974). The drainage area for the Kings River does not include the small part of the basin in Missouri.

[2] Drainage areas for the Neosho River Basin determined at the following U.S. Geological Survey stations: (1) Neosho River below Fort Gibson Lake, near Fort Gibson, Oklahoma (07193500), (2) Spring River near Quapaw, Oklahoma (07188000), (3) Elk River near Tiff City, Missouri (07189000), and (4) Big Cabin Creek near Big Cabin, Oklahoma (07191000). Drainage area for Osage Creek from Terry and others (1984). Drainage areas for Baron Fork and Illinois River Basins determined at the following U.S. Geological Survey stations: (1) Illinois River near Gore, Oklahoma (07198000) and (2) Baron Fork at Eldon, Oklahoma (07197000).

[3] Drainage areas from Homyk and Jeffery (1967). About 960 mi^2 of the South Grand River Basin, 1,000 mi^2 of the Marmaton River Basin, and 270 mi^2 of the Little Osage River Basin are in the study unit. Drainage area for Little Osage River does not include the Marmaton River.

[4] Drainage areas from Homyk and Jeffery (1967).

[5] Drainage area for Meramec River Basin from Homyk and Jeffery (1967); drainage areas for Bourbeuse and Big Rivers from Missouri Department of Natural Resources (1984).

[6] Drainage area for the St. Francis River Basin from U.S. Geological Survey annual Water-Data Report; drainage area in the study unit determined at U.S. Geological Survey station St. Francis River at Wappapello, Missouri (07039500).

[7] Drainage areas from Sullavan (1974). Drainage area for Spring River does not include the Eleven Point River.

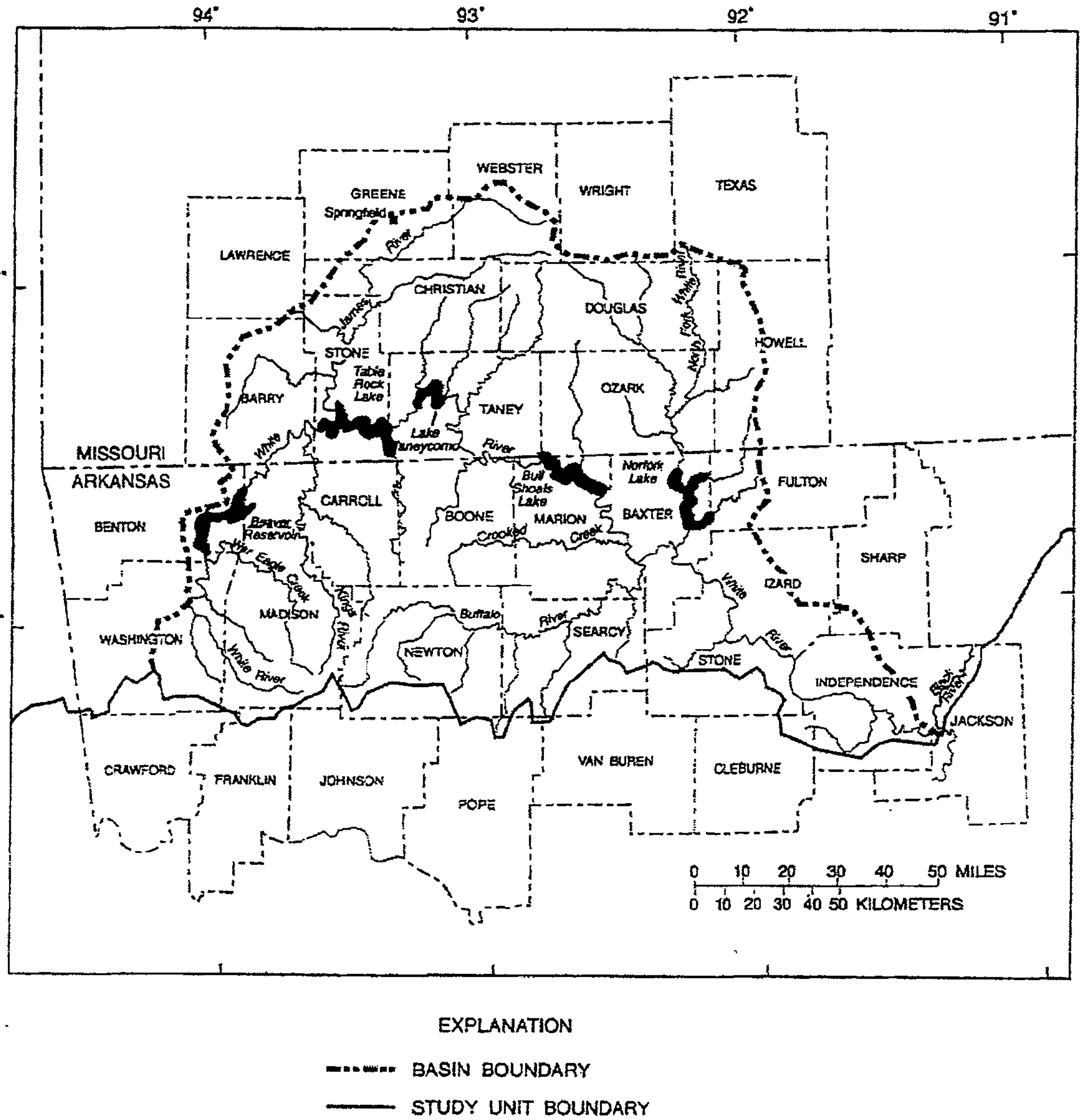

Figure 16. White River Basin with major tributaries and reservoirs.

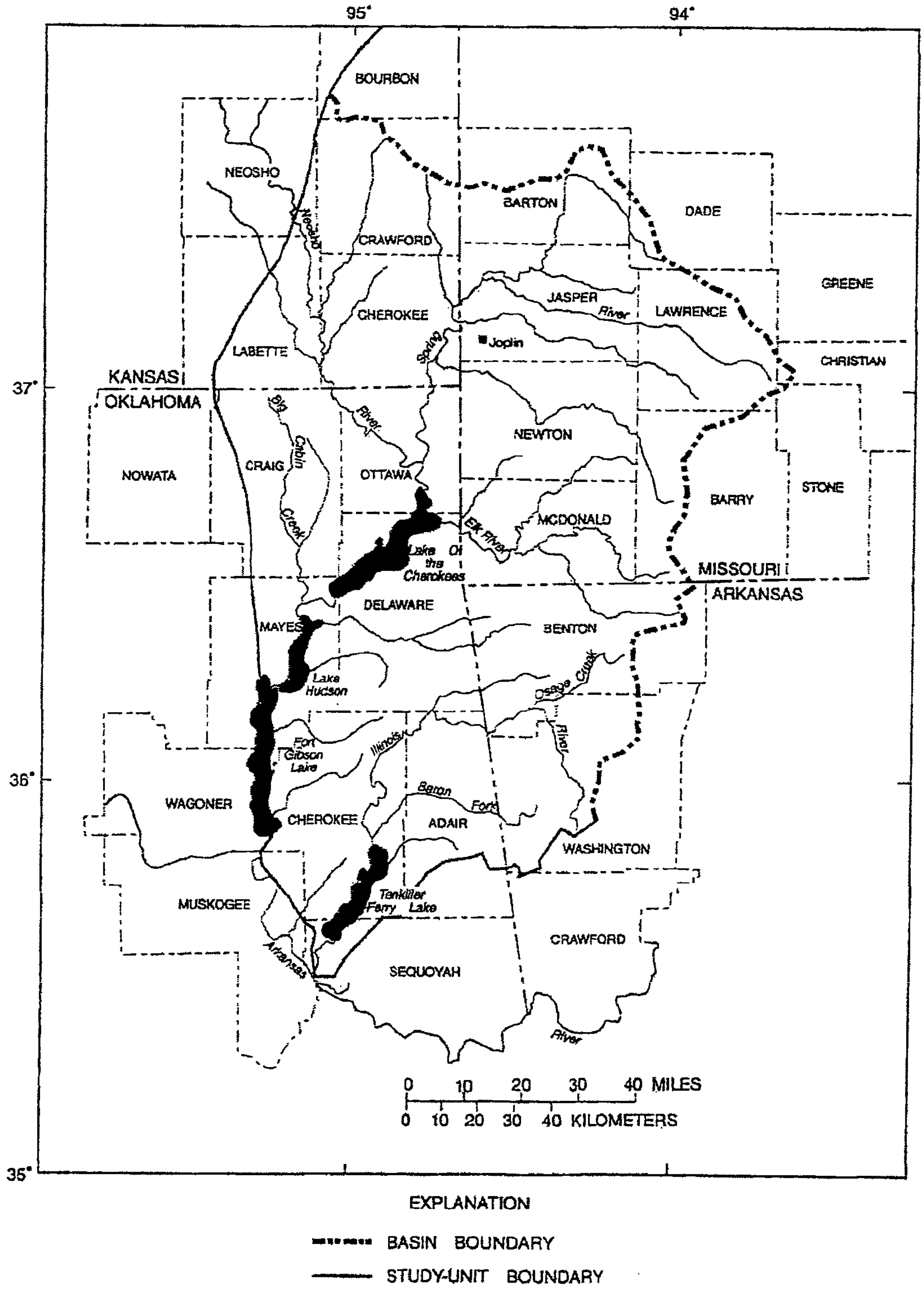

Figure 17. Neosho-Illinois River Basin with major tributaries and reservoirs.

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sas-Oklahoma State line to the upper end of Tenkiller Ferry Lake, the Illinois River has been designated by the Oklahoma State Legislature as a scenic river and is the only river with this designation in Oklahoma.

Osage River

The Osage River originates in east-central Kansas and generally flows eastward into Missouri (fig. 15). In Kansas, the Osage River is called the Marais des Cygnes. The upper two-thirds of the Osage River system, including the Little Osage, Marmaton, and South Grand Rivers, drain the gently rolling prairie land of the Osage Plains (figs. 15 and 18). The South Grand River is the largest tributary to the Osage River and is the only major south-flowing tributary. Land use in this part of the basin is primarily cropland and pasture, although coal has been mined along the western study unit boundary.

The Osage River continues flowing eastward across the Springfield and Salem Plateaus to the Missouri River. About 602 mi of river have been inundated by the construction of four major reservoirs, including Truman Reservoir and Lake of the Ozarks on the main stem (Duchrow, 1984). As in the White and Neosho-Illinois River Basins, the lakes are popular recreational attractions and retirement areas. The total drainage area of the basin is 15,300 mi^2, with 10,700 mi^2 in Missouri and the remainder in Kansas. The drainage area for that part of the basin that lies in the study unit is about 10,500 mi^2.

The Sac River is the only tributary to the Osage River that lies entirely within the Springfield Plateau. Stockton Lake, the third major reservoir in the Osage River Basin, is on the Sac River. About one-half of the Sac River Basin is forested with the remaining land used primarily for cropland or pasture. A small part of this basin is urban. Withdrawals from two small public water-supply lakes and a spring in the Sac River Basin supply much of the drinking water for Springfield, Missouri, which lies on the drainage divide between the James and Sac River Basins.

The Pomme de Terre and Niangua Rivers are the two main Osage River tributaries that lie entirely within the Salem Plateau. Pomme de Terre Lake on the lower Pomme de Terre River is the fourth major reservoir in the Osage River Basin. The resident and tourist populations are not as large at Pomme de Terre Lake as at some of the other recreational reservoirs. Land use in nearly 50 percent of these two basins is agricultural, centered primarily around livestock production.

Gasconade River

The Gasconade River and its major tributary, the Big Piney River, generally flow toward the northeast through the rough terrain of the Salem Plateau to the Missouri River (figs. 15 and 19). No reservoirs or urban areas of any size are located in the basin, which is entirely within the study unit. The total drainage area of the Gasconade River Basin is 3,600 mi^2. At one time, parts of the Gasconade and Big Piney Rivers were considered for inclusion in the Wild and Scenic River System, but because of shoreline development, agricultural activities, and transportation corridors, some segments of the rivers did not meet the eligibility criteria (Bureau of Outdoor Recreation, 1973). The basin is about 75 percent forested; however, livestock and crop production are important land uses in the basin, particularly in the stream valleys.

Meramec River

The Meramec River Basin originates in the Salem Plateau in the northeastern part of the study unit and flows toward the northeast to the Mississippi River just south of St. Louis, Missouri (figs. 15 and 20). Maramec Spring, the seventh largest spring in Missouri, more than doubles the flow of the Meramec River in the upper part of the basin. The entire basin (3,980 mi^2) is in the study unit, with the exception of a small part in the St. Louis metropolitan area. The upper part of the basin is primarily forested with some cropland and pasture. Small tributaries to the upper Meramec River drain part of the Viburnum Trend mining area.

The Meramec River has two major tributaries, the Bourbeuse River on the north and the Big River on the east. Much of the basin of the Bourbeuse River, which flows from west to east along the northern part of the Meramec River Basin, is underlain by undifferentiated deposits of Pennsylvanian age, which overlie and sometimes fill depressions in an ancient karst topography developed in deposits of Ordovician age (Vineyard and Feder, 1974). The gently rolling terrain is suitable for agricultural land uses, and the Bourbeuse River Basin has more pasture and tilled lands than other parts of the Meramec River Basin. The Big River originates in the St. Francois Mountains and flows northward through the Salem Plateau to the Meramec River. The

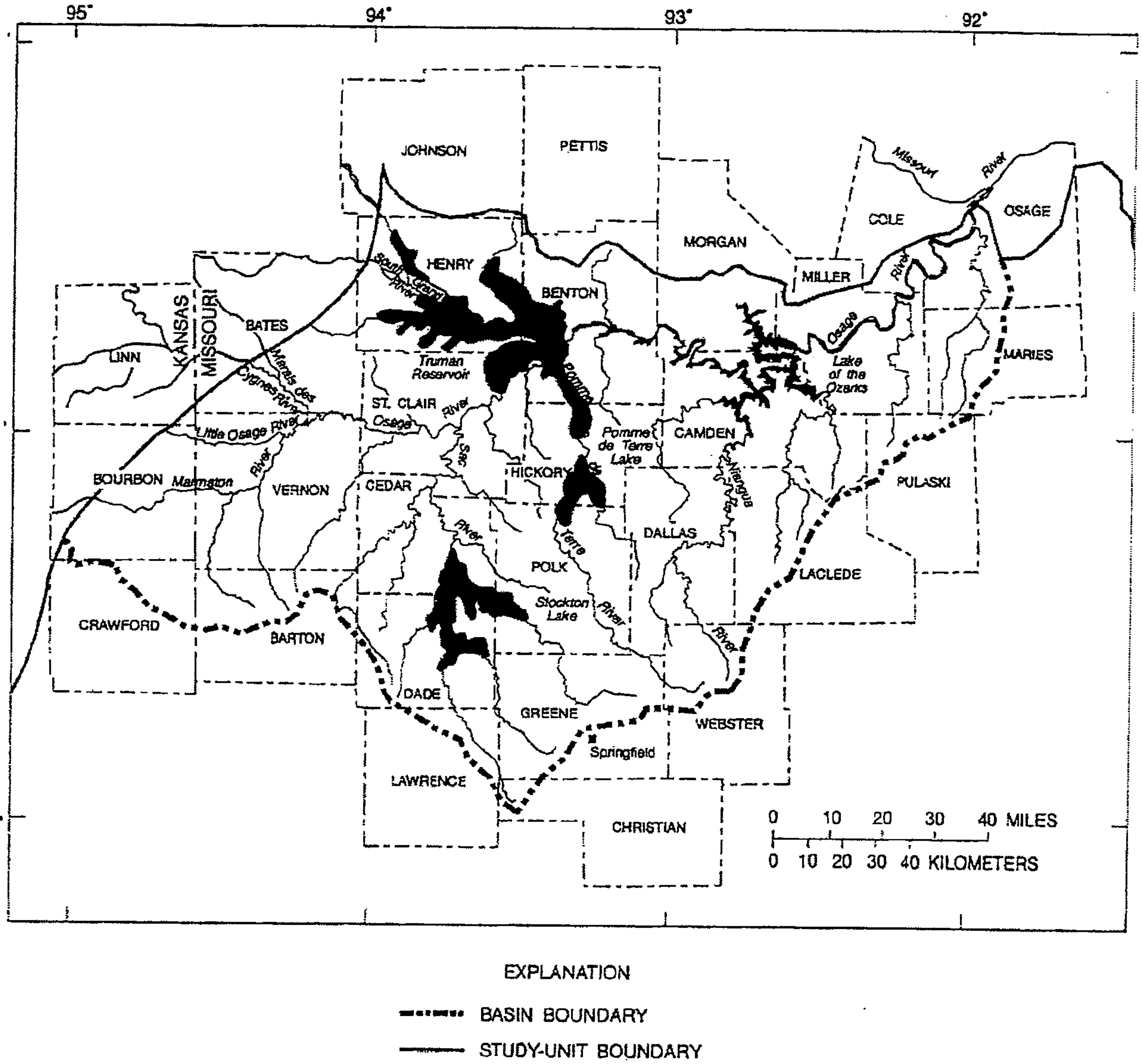

Figure 18. Osage River Basin with major tributaries and reservoirs.

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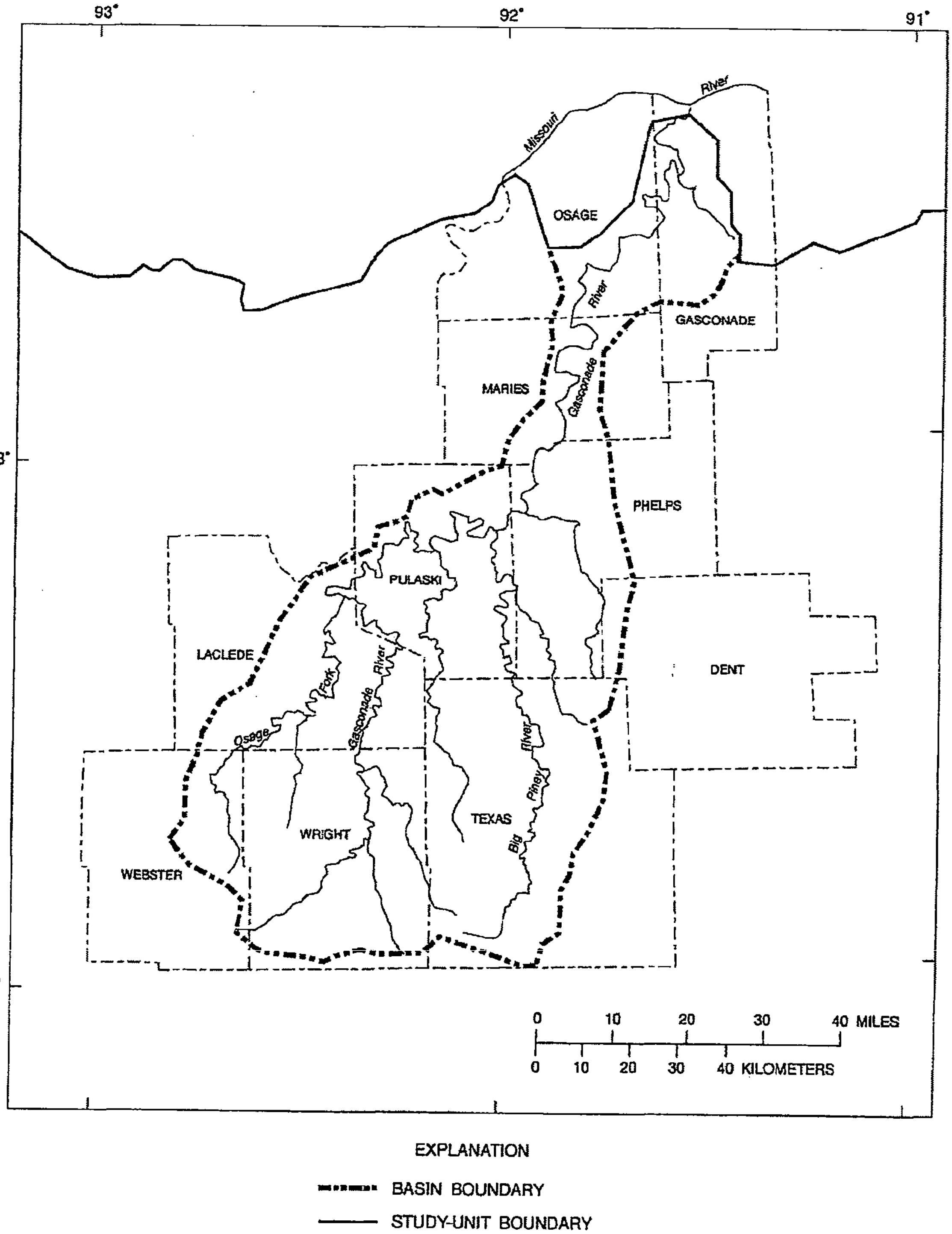


Figure 19. Gasconade River Basin with major tributaries.

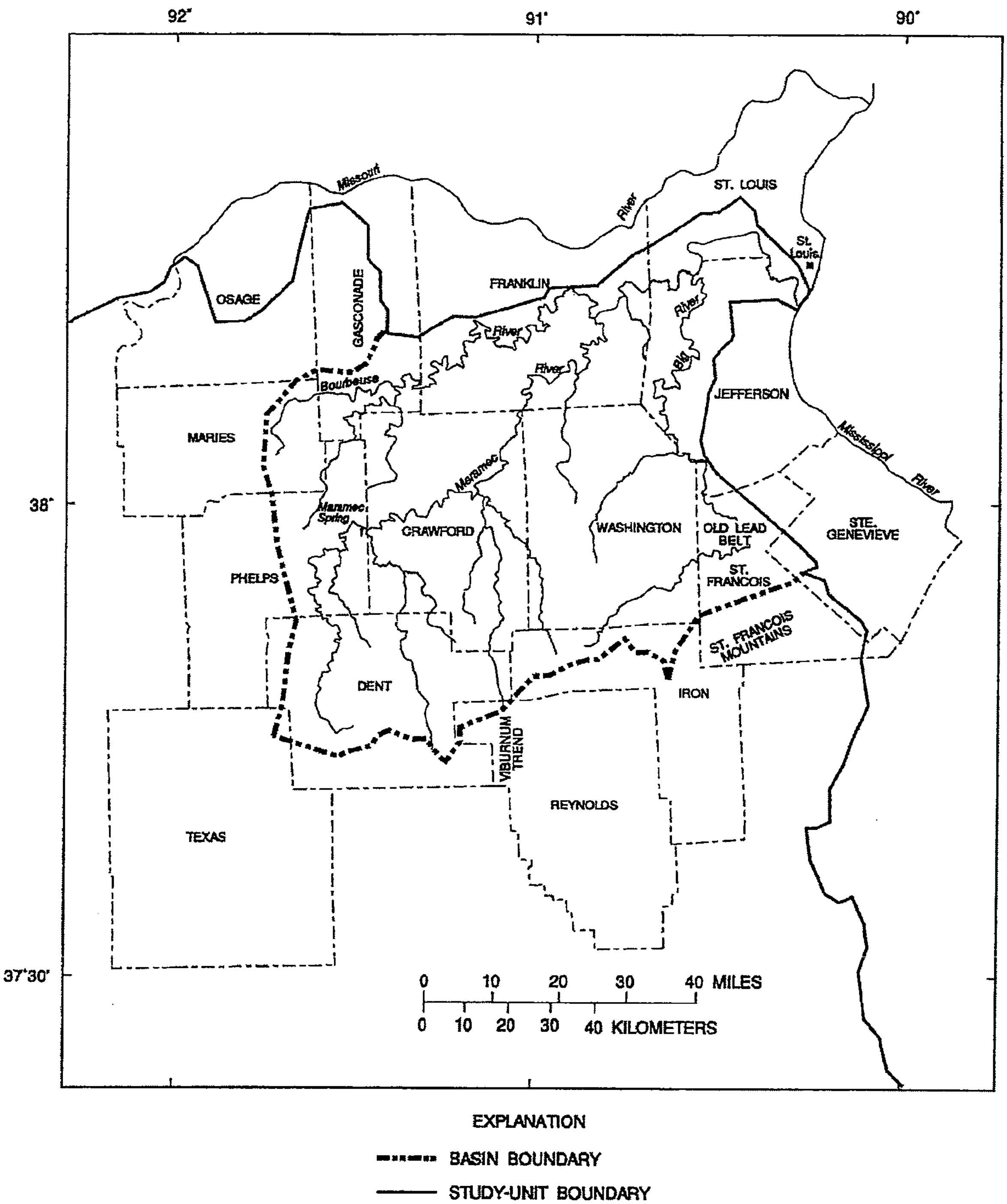


Figure 20. Meramec River Basin with major tributaries and spring.

Big River Basin encompasses much of the Old Lead Belt mining area and most of the area of past and present barite mining.

St. Francis River

The St. Francis River originates in the southern flank of the rugged St. Francois Mountains of southeastern Missouri and flows toward the south through the Salem Plateau out of the study unit into Arkansas to the Mississippi River (figs. 15 and 21). The total drainage area of the basin is about 6,480 mi^2, with only about 1,310 mi^2 in the study unit. Lake Wappapello, located at the southeastern extent of the basin in the study unit, is a major recreation area. Like other basins in the Salem Plateau, the basin is predominantly forested with some pasture, although some lead and zinc have been mined in the upper part of the basin.

Black River

The Black River is the largest tributary (8,560 mi^2) to the White River system. Major tributaries to the Black River include the Current, Eleven Point, Spring, and Strawberry Rivers. The Strawberry River Basin lies wholly in north-central Arkansas, but the headwaters and much of the drainage area of the other major tributaries of the Black River are in southern Missouri. Like the St. Francis River, the Black River originates on the southern flank of the St. Francois Mountains and flows southward through the Salem Plateau into Arkansas to the White River (figs. 15 and 22). On the eastern side of the river, a small part of the drainage area is in the Mississippi Alluvial Plain. The other tributaries lie entirely in the Salem Plateau. The only major reservoir in the basin, Clearwater Lake, is on the Black River in Missouri. At least 50 percent of the land is forested in all of the basins with the remainder used primarily for pasture and cropland; no major urban areas are in the Black River Basin. Small tributaries to the upper Black River drain the southern end of the Viburnum Trend mining area.

The Black River Basin is characterized by rugged, hilly countryside, numerous springs, and clear, fast-flowing streams. The three largest springs in the study unit are in the Black River Basin: Greer Spring (average flow of 289 ft^3/s) on the Eleven Point River, Mammoth Spring (measured flows ranged from 240 to 431 ft^3/s) on the Spring River, and Big Spring (average flow of 428 ft^3/s; Vineyard and Feder, 1974) on the Current River. In 1974, 134 mi of the Current River and its principal tributary, Jacks Fork, and about 65,000 acres of adjoining land were designated as the Ozark National Scenic Riverways (Barks, 1978) to preserve the natural conditions of the Current River Basin and to increase recreational opportunities for fishermen, canoeists, and campers. A part of the Eleven Point River in Missouri also has been designated as a National Scenic River.

Stream Morphology

Some of the major rivers and their tributaries lie totally within a single physiographic section; however, more typically, a large stream will flow through two or more physiographic sections and, as it does, the stream morphology changes. Descriptions of typical stream morphology for each of the physiographic sections or areas follow.

The terrain in the Boston Mountains is exceptionally steep and rugged with local relief as much as 1,000 ft in places (Bennett and others, 1987). Because of the rugged terrain and steep slopes, streams have high gradients, averaging about 20 ft/mi (Giese and others, 1987). Stream beds consist predominantly of bedrock and rubble with smaller amounts of boulders, gravel, and sand.

Relief in the Springfield and Salem Plateaus generally is less than that in the Boston Mountains. Valleys generally are deeper and narrower and the ridges sharper in the Salem Plateau than in the Springfield Plateau. Local relief along the major streams often exceeds 300 ft (Pflieger, 1989) and is as much as 500 ft in some areas. Stream channels in the Springfield and Salem Plateaus consist of a series of well-defined riffles and pools, and channel beds consist predominantly of coarse gravel, rubble, boulders, and bedrock. Stream gradients generally exceed 3 ft/mi even in the larger streams and are as much as 50 ft/mi in some headwater areas (Pflieger, 1989). The water usually is quite clear. In some areas of the Springfield and Salem Plateaus, forests have been cleared to develop land for agricultural purposes resulting in a reduction in the tree canopy overhanging streams. This reduction allows more sunlight to reach the stream, which can increase water temperatures and the growth of aquatic vegetation.

Streams in the St. Francois Mountains within the Salem Plateau have high stream gradients. Pflieger (1989) does not differentiate between the morphology

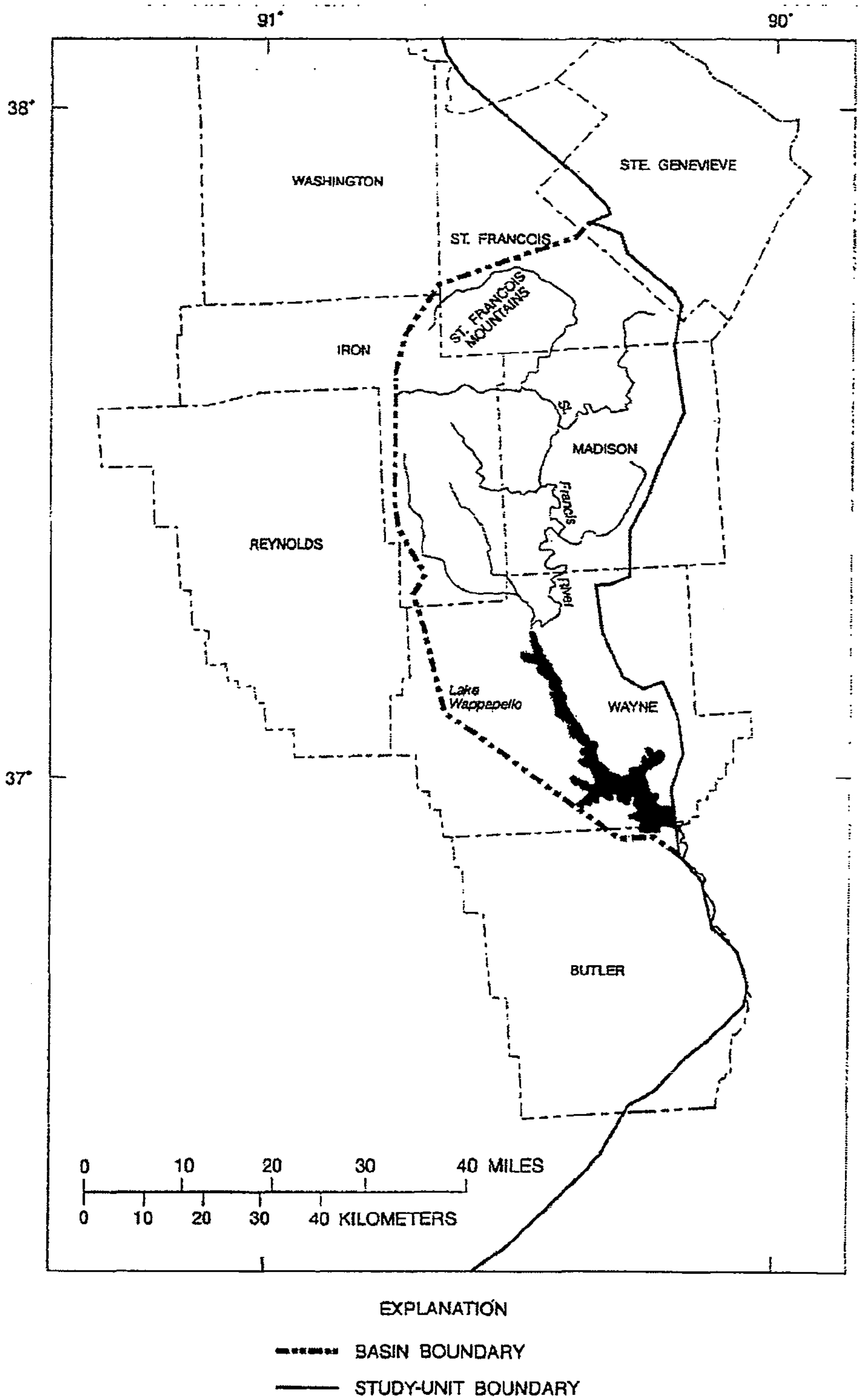


Figure 21. St. Francis River Basin with major tributaries and reservoir.

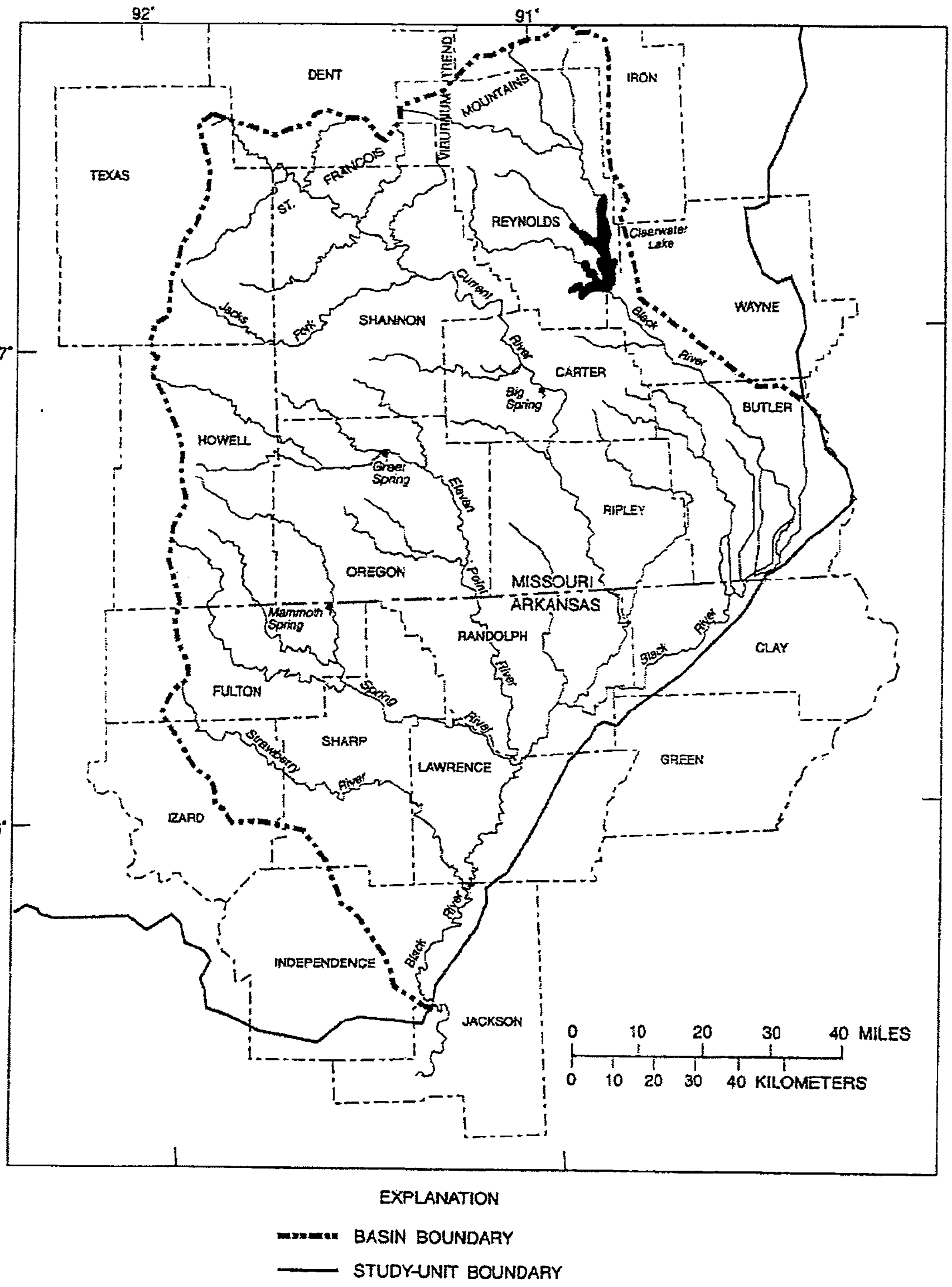


Figure 22. Black River Basin with major tributaries, reservoir, and springs.

of the St. Francois Mountains and the rest of the Salem Plateau. Therefore, the morphology of streams in the St. Francois Mountains probably is similar to that of streams in other parts of the Salem Plateau; however, stream gradients are as much as 200 ft/mi in some headwater stream reaches. A distinctive valley form, called a shut-in, is formed where streams erode resistant igneous rocks in the St. Francois Mountains. The results are steeply sided valleys and cascading waterfalls (Beveridge and Vineyard, 1990).

Streams in the Osage Plains occupy broad, shallow valleys and, if unchannelized, follow meandering courses. Gradients average about 26 ft/mi in headwater areas but average less than 2 ft/mi in the larger streams (Pflieger, 1989). Channels consist of long pools, and riffles are often nonexistent or poorly defined. Sand and silt channel beds are dominant in the pools; shale and sandstone gravel and pebbles are dominant in the riffles.

Streams in the Mississippi Alluvial Plain meander through a broad alluvial plain. Oxbow lakes are common along the lower reach of the Black and Current Rivers. Many of the streams have been channelized. Maximum relief is only a few feet per mile (Bennett and others, 1987). Stream gradients generally are less than 1 ft/mi. The channel bed in swifter areas of streams and ditches is mostly sand and gravel; in areas of less velocity, the channel bed is usually silt (Pflieger, 1989).

Runoff and Streamflow

Runoff can be defined as the water that drains from the land into stream or river channels after precipitation and is a function of precipitation amounts, topography, geology, soil moisture, and other factors. Mean annual runoff per square mile of basin, which can be computed by dividing the mean annual volume of water leaving the basin (measured as streamflow at a gaging station) by the area of that basin, is often used for purposes of comparing runoff characteristics between basins.

Mean annual runoff within the Ozark Plateaus study unit is shown in figure 23 (Gebert and others, 1987). Mean annual runoff generally is least in the Osage Plains where it ranges from about 9 to 10 in. Mean annual runoff in the Springfield and Salem Plateaus, and St. Francois Mountains generally ranges from 10 to 15 in., although values are more variable in the eastern Salem Plateau where they range from about 4 to 30 in. (Hedman and others, 1987). Mean annual runoff is about 16 in. in the Mississippi Alluvial Plain within the study unit (Neely, 1986). The mean annual runoff generally is greatest in the Boston Mountains where it ranges from 14 to 20 in.

Magnitude, frequency, and duration of floods and high streamflows are affected by many factors, including drainage area, basin and channel slope, channel length, precipitation amount and intensity, vegetation, season, and flow-regulation activities or structures. Flood-frequency and flood-magnitude information for streams in the study unit are available in reports for Arkansas (Neely, 1987), Kansas (Jordan and Irza, 1975), Missouri (Sandhaus and Skelton, 1968; Hauth, 1974), and Oklahoma (Sauer, 1974; Thomas and Corley, 1977).

Duration of high streamflows (and the time lag between onset of precipitation and the peak flow) generally will be shortest in small, steep basins. The location of streamflow stations and hydrographs that exemplify this type of response for the Neosho River and Lightning Creek in the Osage Plains, and the Current River and Jacks Fork in the Salem Plateau are shown in figures 24 and 25. Streamflow is elevated for longer periods of time in the Osage Plains streams and in the streams with larger drainage areas. Although these examples are typical, the duration and magnitude of streamflow peaks at a specific location are strongly dependent on antecedent precipitation and precipitation intensity, duration, and distribution.

Annual mean streamflow of individual streams within the Ozark Plateaus study unit can vary substantially from year to year (fig. 26). Between 1951 and 1990, there were periods of low flows in the mid-1950's, mid-1960's, and early 1980's, and periods of generally high flows in the early 1950's, early and late 1960's, mid-1970's, and mid-1980's. Annual mean streamflows for water year 1981 were extremely low throughout the study unit but annual mean streamflows just 4 years later, in 1985, were among the highest for the period of record. Although, these patterns generally are regionally consistent, local climatological differences also affect annual mean streamflows.

Runoff and streamflow also vary seasonally. Minimum monthly streamflows typically occur in summer and fall, July through October (fig 27). Maximum monthly streamflows typically occur in spring, March through May (fig. 27). These seasonal variations in streamflow primarily are the result of seasonal differ-

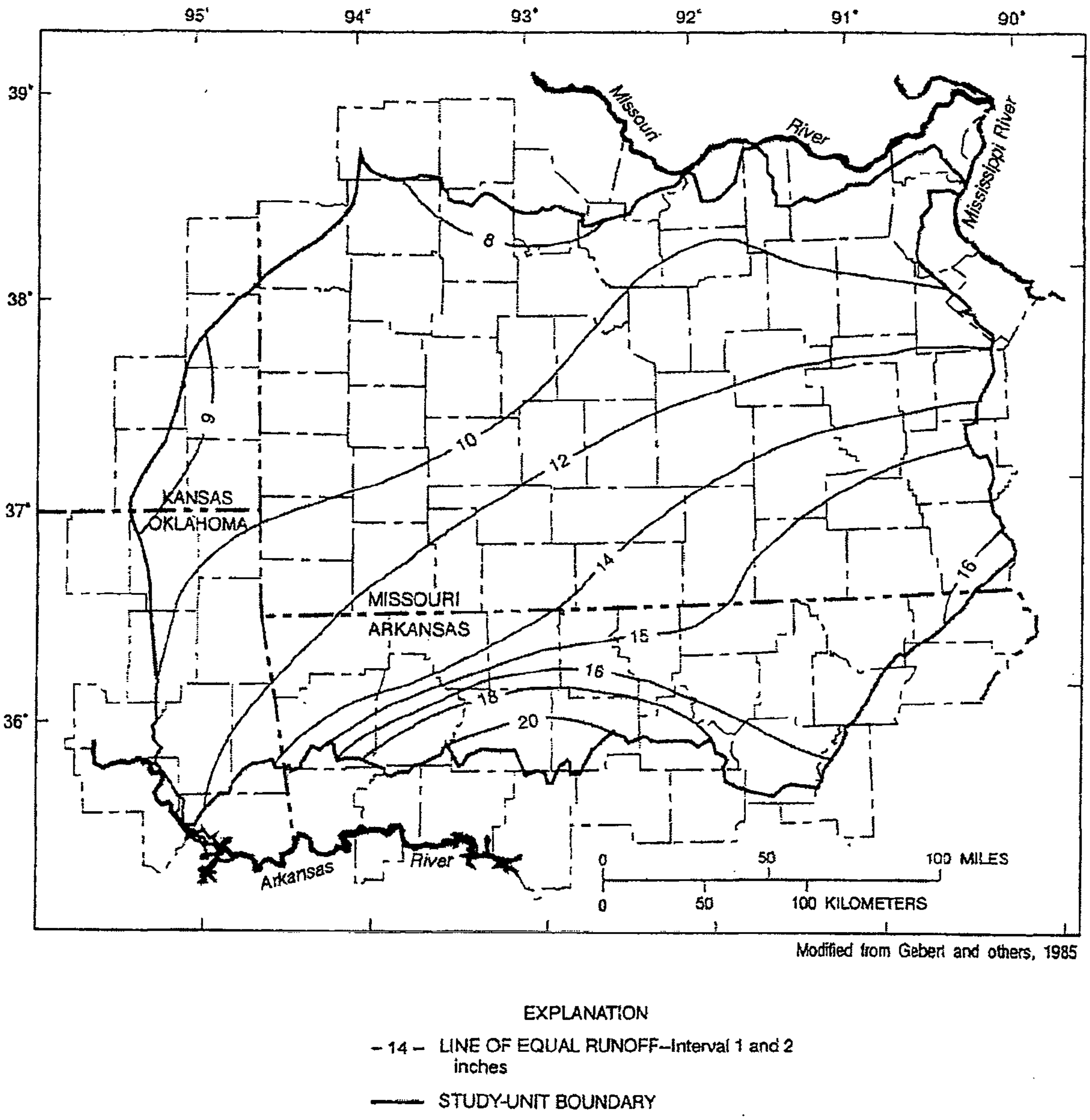


Figure 23. Mean annual runoff in the Ozark Plateaus study unit, 1951-80.

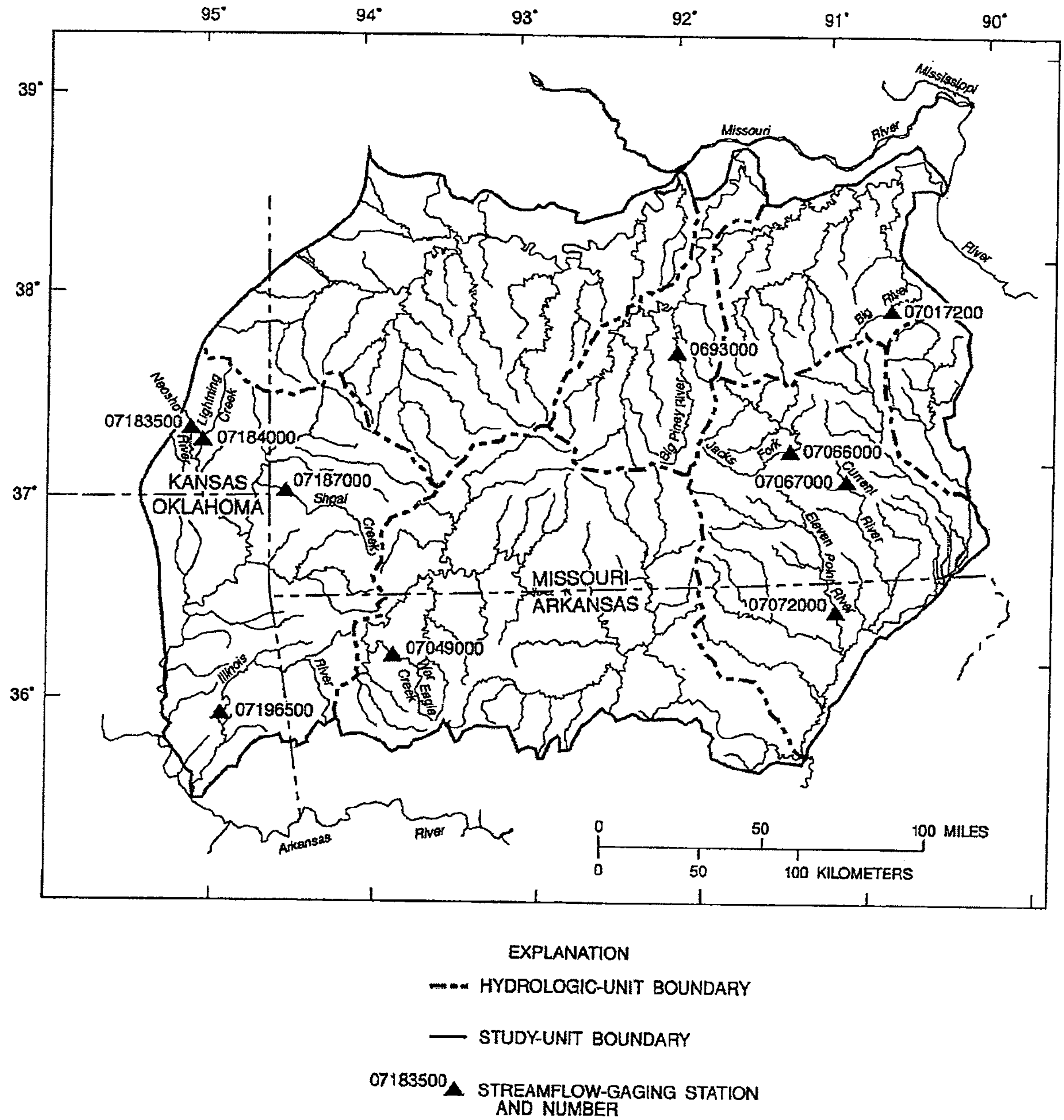


Figure 24. Location of selected streamflow-gaging stations in the Ozark Plateaus study unit.

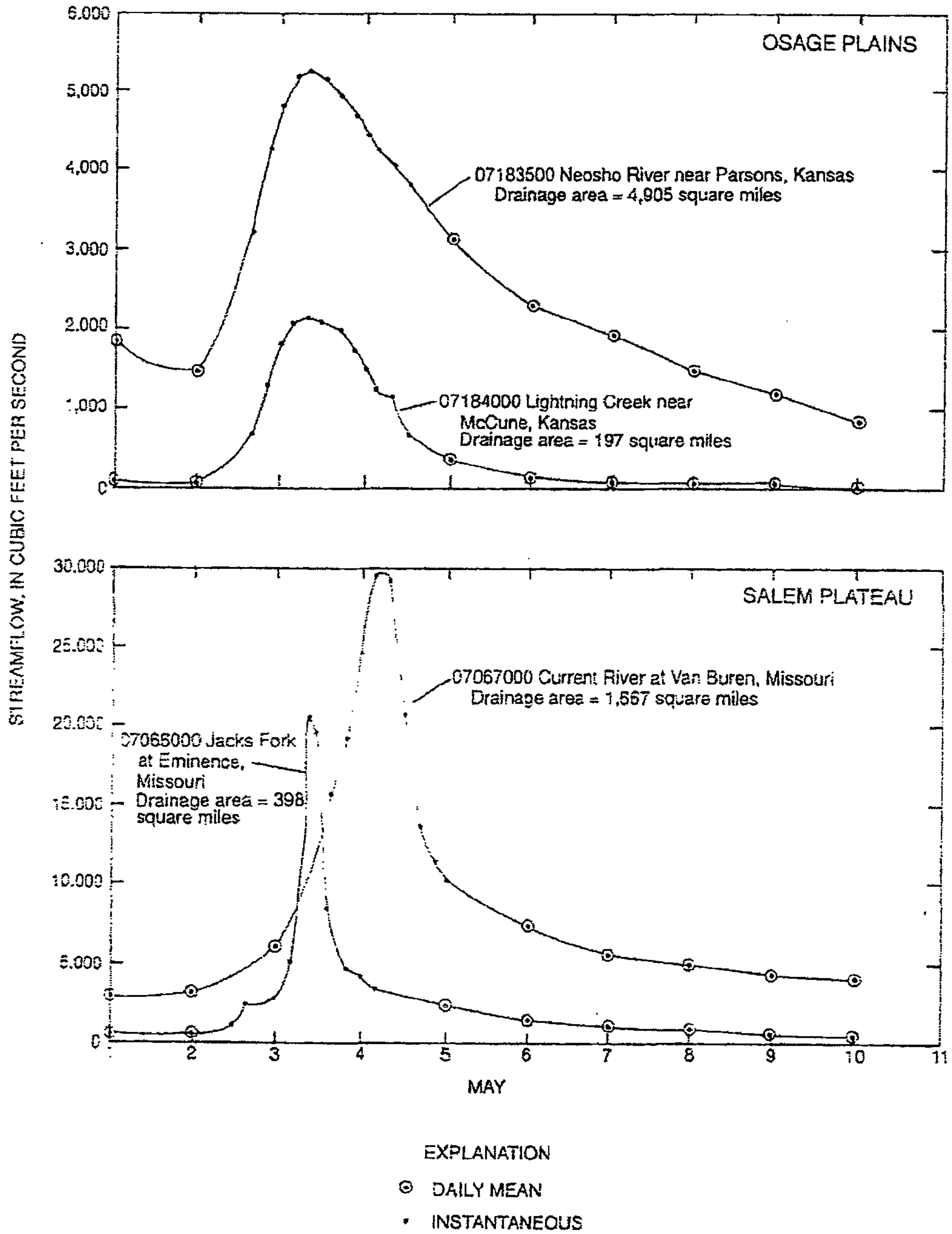


Figure 25. Streamflow at Neosho River near Parsons, Lightning Creek near McCune, Current River at Van Buren, and Jacks Fork at Eminence, May 1-10, 1990.

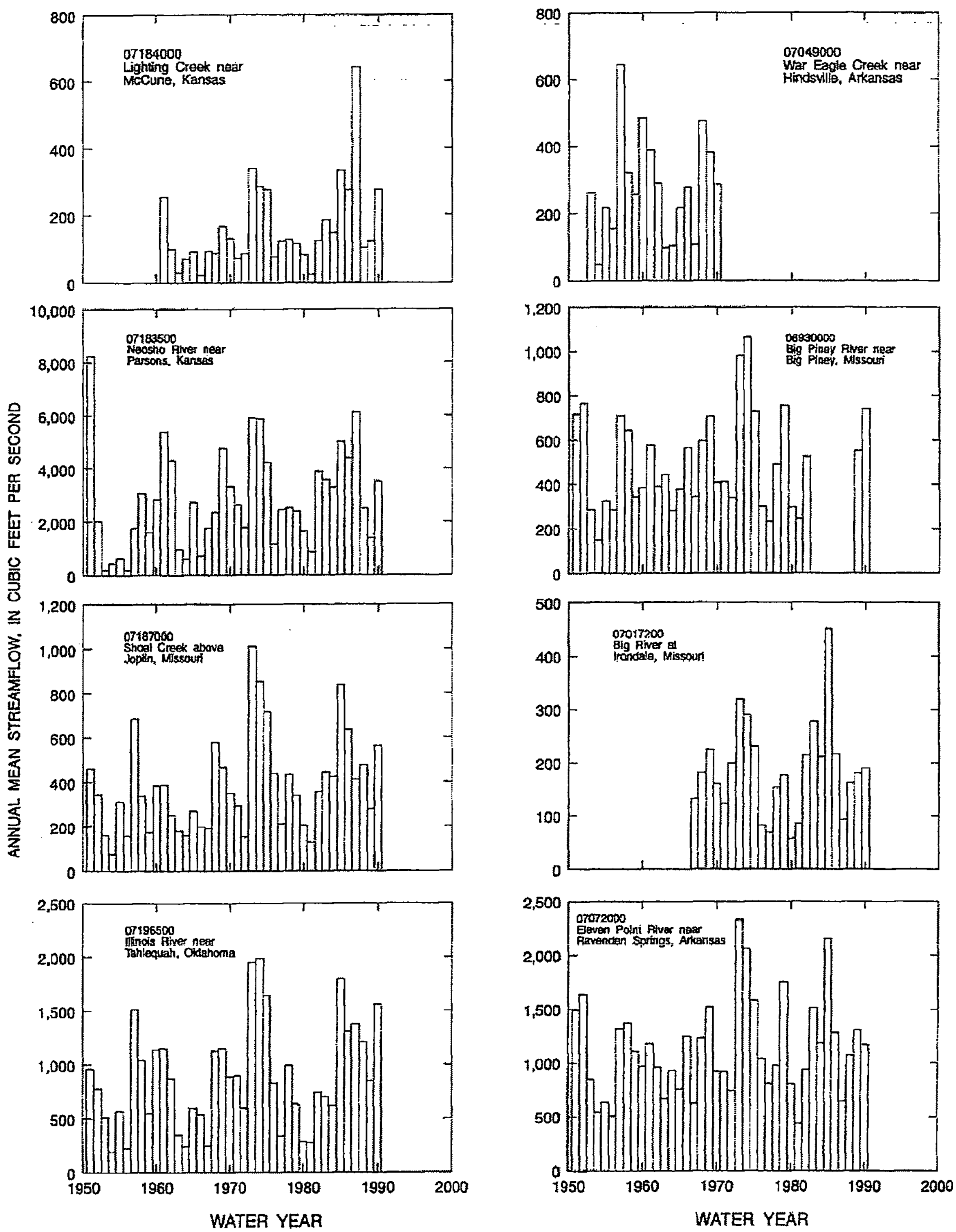


Figure 26. Annual mean streamflow for selected stations in the Ozark Plateaus study unit.

ences in evapotranspiration and precipitation. Potential evapotranspiration is much lower during October through March (about 6 to 10 in.) than in April through September (about 37 to 42 in.; Dugan and Peckenpaugh, 1985). Evapotranspiration probably has a greater effect than precipitation on low flow. For example, in northwestern Arkansas, January and February generally are the driest months (Freiwald, 1985), but streamflows generally are lowest in August and September when evapotranspiration rates are higher (fig. 27). Maximum monthly precipitation and streamflow in this area generally occurs in March through May.

The interaction between surface- and ground-water flow systems is a function of factors such as geology, soil type, and topography and can differ substantially between basins and between physiographic sections or areas. In general, interaction is less in the Osage Plains, Boston Mountains, and St. Francois Mountains and greater in the Springfield Plateau, Salem Plateau, and Mississippi Alluvial Plain. The amount of interaction generally can be characterized by flow-duration curves, dye-tracing and seepage-run studies, and ground-water level information. Streams with sustained dry-season flow (base flow) have a large ground-water contribution to streamflow and streams with little or no dry-season flow receive relatively little ground water and in some instances lose water to the ground-water system.

Interaction between the surface- and ground-water flow systems in the Osage Plains is rather limited and streams in the area have little base flow. Flow-duration curves for streams in the Osage Plains have relatively steep slopes, indicating extremely variable streamflow largely from surface runoff (Hedman and others, 1987). These streams are not well-sustained by ground-water discharge during periods of little rainfall because they are underlain by relatively impermeable shales and sandstones. Ground-water levels in the Osage Plains generally do not fluctuate substantially with season (except where affected by pumping), which indicates that vertical recharge of the ground water is limited (Gann and others, 1974).

Interaction between the surface- and ground-water flow systems also is limited in the Boston Mountains. Flow-duration curves for streams in the Boston Mountains indicate extremely variable streamflow, largely from surface runoff (Hedman and others, 1987). No streams in the Boston Mountains are perennial (Hunrichs, 1983) and few springs exist.

Surface- and ground-water flow system interaction also is limited in the St. Francois Mountains. Flow-duration curves (Hedman and others, 1987) for gaging stations on some streams in this area are similar to flow-duration curves for stations on streams in the Osage Plains and Boston Mountain; curves for stations on other streams are intermediate between the Osage Plains and Boston Mountain curves and curves typical of the Springfield and Salem Plateaus. Few springs exist in areas in the St. Francois Mountains underlain by igneous rocks.

Interaction between the surface- and ground-water flow systems is much greater in the Springfield and Salem Plateaus than in the Osage Plains, Boston Mountains, and St. Francois Mountains. Flow-duration curves for streams in these areas have relatively flat slopes, indicating a well-sustained flow from surface- or ground-water storage (Hedman and others, 1987). Streams in the Salem Plateau north of the Osage River generally have less base flow than streams south of the Osage River. Seasonal ground-water level fluctuations typically are greater in the Springfield and Salem Plateaus than in the Osage Plains, indicating that solution openings are well developed and that recharge occurs locally (Gann and others, 1974). Freiwald (1987), in a study of streamflow gain and loss for several streams in northern Arkansas, determined that for most of the length of the studied streams in the Springfield and Salem Plateaus, these streams were gaining streamflow through ground-water contributions. Short reaches where the streams recharge the ground-water system through losing stream channels also were identified. In Missouri, many basins or stream reaches exist where substantial quantities of flow are known to be lost to the subsurface drainage, particularly in the Eleven Point, Current, and Meramec River Basins (Gann and others, 1976). Dye-tracing studies indicate that interbasin transfers are common.

A moderate amount of interaction occurs between the surface- and ground-water flow systems in the Mississippi Alluvial Plain. Flow-duration curves for streams in this area of the study unit have relatively flat slopes, indicating a well-sustained flow from surface- or ground-water storage (Hedman and others, 1987). Model simulations indicate that the Black River is a losing river in southern Missouri and northern Arkansas but is a gaining river in most of its length downstream from the mouth of the Current River (Ackerman, 1989, p. 66). Water levels at some locations in the alluvial aquifer are known to fluctuate with

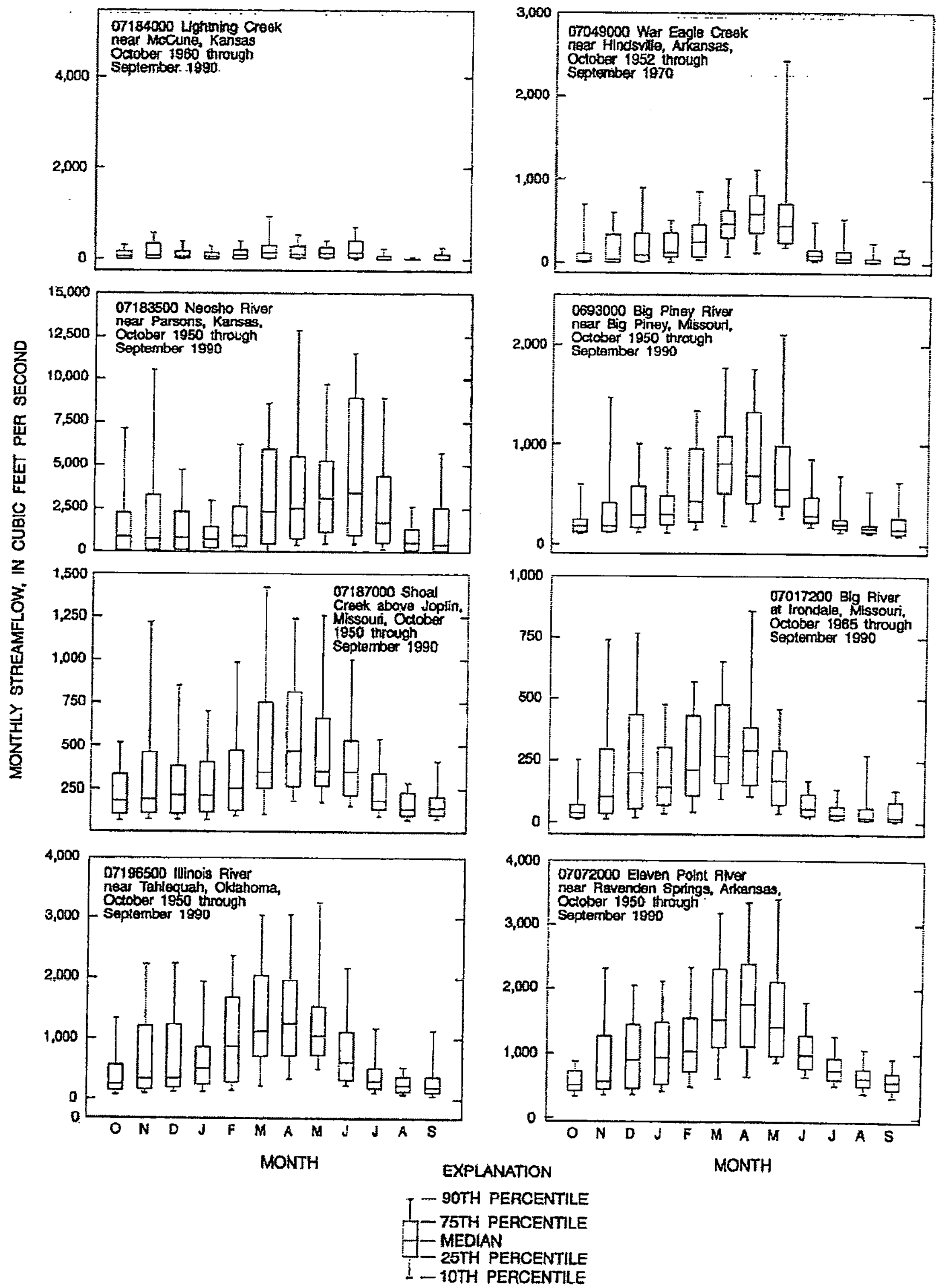


Figure 27. Monthly streamflow variations for selected stations in the Ozark Plateaus study unit.

streamflow (Albin and others, 1967; Lamonds and others, 1969).

Water Quality

The ambient or natural water quality of streams and rivers in the study unit differ as a result of differences in geology and physiography in the basins and differences in the amount of surface- and ground-water interaction. Typical ranges of selected water-quality characteristics of streams in the study unit are listed by physiographic section or area in table 5. These data have been compiled from reports by Lamonds (1972), Gann and others (1974; 1976), Stoner (1981), Bennett and others (1987), and Petersen (1988) and from USGS water-quality computer files. These ranges are typical of characteristics in relatively large streams and rivers during periods of near average flow. Water-quality characteristics during periods of low or high flow would likely be substantially different from those presented in table 5. Only water-quality data for streams and rivers "relatively unaffected" by human activities were used to calculate these ranges. Because of agricultural activities and higher population density in the Osage Plains and Springfield Plateau, a "relatively unaffected" stream in these two areas probably is more affected by human activities than streams in other areas.

Streams in the Osage Plains generally are the most mineralized streams in the study unit. Water in Osage Plains streams typically is a calcium bicarbonate type with substantial amounts of sodium, magnesium, and sulfate. Sulfate concentrations in Osage Plains streams and rivers generally are 5 to 10 times higher than those in most other streams and rivers in the study unit; chloride concentrations are about 2 times higher than concentrations in most other streams.

Streams in the Boston Mountains generally are the least mineralized streams in the study unit; dissolved-solids concentrations in water in those streams commonly are one-fifth to one-half of the dissolved-solids concentrations in water from streams in other areas. Water in these streams generally is a calcium bicarbonate type and commonly is more acidic and has lower buffering capacity (lower alkalinity) than water in streams from other areas. Nutrient concentrations (for example, nitrite plus nitrate) are relatively low. Nutrient concentrations in water from streams in the Boston Mountains generally are among the lowest nutrient concentrations for Arkansas streams (Petersen, 1988).

Water-quality values for streams and rivers in the Springfield and Salem Plateaus typically are quite similar. However, dissolved-solids concentrations and alkalinity are somewhat lower in water from some streams in the Springfield Plateau than in water from streams in the Salem Plateau. Most of the streams with relatively low dissolved-solids concentrations in water flow from the Boston Mountains into the Springfield

Table 5. Typical ranges of selected physical and chemical characteristics of surface water in the Ozark Plateaus study unit

[Ranges shown represent median values for individual stations. Water quality of small streams might not be reflected by these data. Individual medians that were considered to be outliers are not included in these ranges; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate]

Physiographic section or area	Dissolved solids (mg/L)	pH (units)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Alkalinity[1] (mg/L as $CaCO_3$)	Nitrite plus nitrate, total as nitrogen (mg/L)
Osage Plains	220-280	7.4-7.8	8-20	20-45	140-210	0.1 -0.9
Boston Mountains	40- 60	6.8-7.3	3- 5	5-10	15- 20	.05 - .2
Springfield Plateau	100-200	7.5-8.0	4-10	5-10	100-175	.2 -1.5
Salem Plateau[2]	150-210	7.5-8.1	2- 8	3-12	150-200	.2 - .8
St. Francois Mountains	110-130	7.5-8.0	2- 5	8-17	75-110	.1 - .3
Mississippi Alluvial Plain	140-170	7.9-8.0	3- 5	4- 8	110-150	.1 - .3

[1] Alkalinity as $CaCO_3$ can be converted to bicarbonate (HCO_3) by multiplying by 1.22.
[2] Values not included for streams in the St. Francois Mountains.

Plateau. Water in most streams in the Springfield Plateau is a calcium bicarbonate type, and water in most streams in the Salem Plateau is a calcium magnesium bicarbonate type. Nitrite plus nitrate nitrogen concentrations in some Springfield Plateau streams that are relatively unaffected by human activities are higher than concentrations in most Salem Plateau streams. Population and land-use differences between the Springfield and Salem Plateaus indicate that the water quality of streams in the Springfield Plateau is more likely to be affected by human activities than is water quality of streams in the Salem Plateau.

Streams in the St. Francois Mountains are more mineralized than streams in the Boston Mountains but less mineralized than many streams in the rest of the study unit. Dissolved-solids concentrations of water from the southward-flowing streams draining the St. Francois Mountains commonly are about 120 mg/L and dissolved sulfate concentrations commonly range from about 8 to 17 mg/L. Water in streams in the St. Francois Mountains typically is a calcium magnesium bicarbonate type. Nitrite plus nitrate nitrogen concentrations in streams in the St. Francois Mountains are the lowest in the study unit with the exception of streams in the Boston Mountains and Mississippi Alluvial Plain.

The quality of the water in the larger streams in the part of the study unit in the Mississippi Alluvial Plain is similar to the quality of water in streams in the Salem Plateau because a large part of the drainage area of these streams is within the Salem Plateau. Streams in this area generally contain a calcium magnesium bicarbonate water with dissolved-solids concentrations commonly between 140 and 170 mg/L.

GROUND WATER

Ground water is an abundant resource in most of the Ozark Plateaus study unit. Ground water is present in intergranular pore spaces and in fractures of the sandstones, limestones, and dolomites (Imes and Emmett, 1994).

Ground-water divides in the shallow aquifers generally coincide with topographic divides. Ground-water level altitudes are highest in the Boston Mountains and along the major topographic ridge extending across southern Missouri, which form regional ground-water divides. Ground water flows away from these regional divides; water flowing in the deep part of the aquifer system discharges into the major rivers of the area (fig. 28). Ground water moving through the shallow part of the aquifer system follows short (usually less than 10 mi), local flow paths that terminate at nearby streams (Imes and Emmett, 1994).

Regional boundaries for the ground-water flow system in the Ozark Plateaus study unit and adjacent areas include the Missouri and Mississippi Rivers to the north and northeast, respectively. To the southeast, ground water discharges into the unconsolidated sediments of the Mississippi Alluvial Plain. The topographic divide along the crest of the Boston Mountains forms the southern boundary. The western boundary is formed by a broad, topographically low area where freshwater mixes with saline water along the transition zone between the Ozark Plateaus aquifer system and the Western Interior Plains aquifer system (Imes and Emmett, 1994).

Hydrogeology

The ground-water system in the Ozarks Plateaus study unit can be divided into seven major regional hydrogeologic units based on relative rock permeabilities and well yield. The hydrogeologic units consist of three main aquifers and four confining units that coincide with the major geologic units and physiographic sections of the study unit (fig. 7). These units include the Western Interior Plains confining system, the Springfield Plateau aquifer, the Ozark confining unit, the Ozark aquifer, the St. Francois confining unit, the St. Francois aquifer, and the Basement confining unit (fig. 29). The middle five units comprise the Ozark Plateaus aquifer system, and are confined above and below by the Western Interior Plains confining system and the Basement confining unit, respectively (fig. 30; Imes and Emmett, 1994). The unconsolidated sediments of Post-Paleozoic age in the Mississippi Alluvial Plain are productive aquifers in a small part of the study unit, but the ground-water resources of these sediments will not be discussed in this report.

Western Interior Plains Confining System

The Western Interior Plains confining system coincides with parts of two physiographic sections--the Boston Mountains in the southern part of the study unit and the Osage Plains in the western part of the study unit (fig. 29). Rocks of late Mississippian to Pennsylvanian age form the confining system (fig. 7). Equivalent,

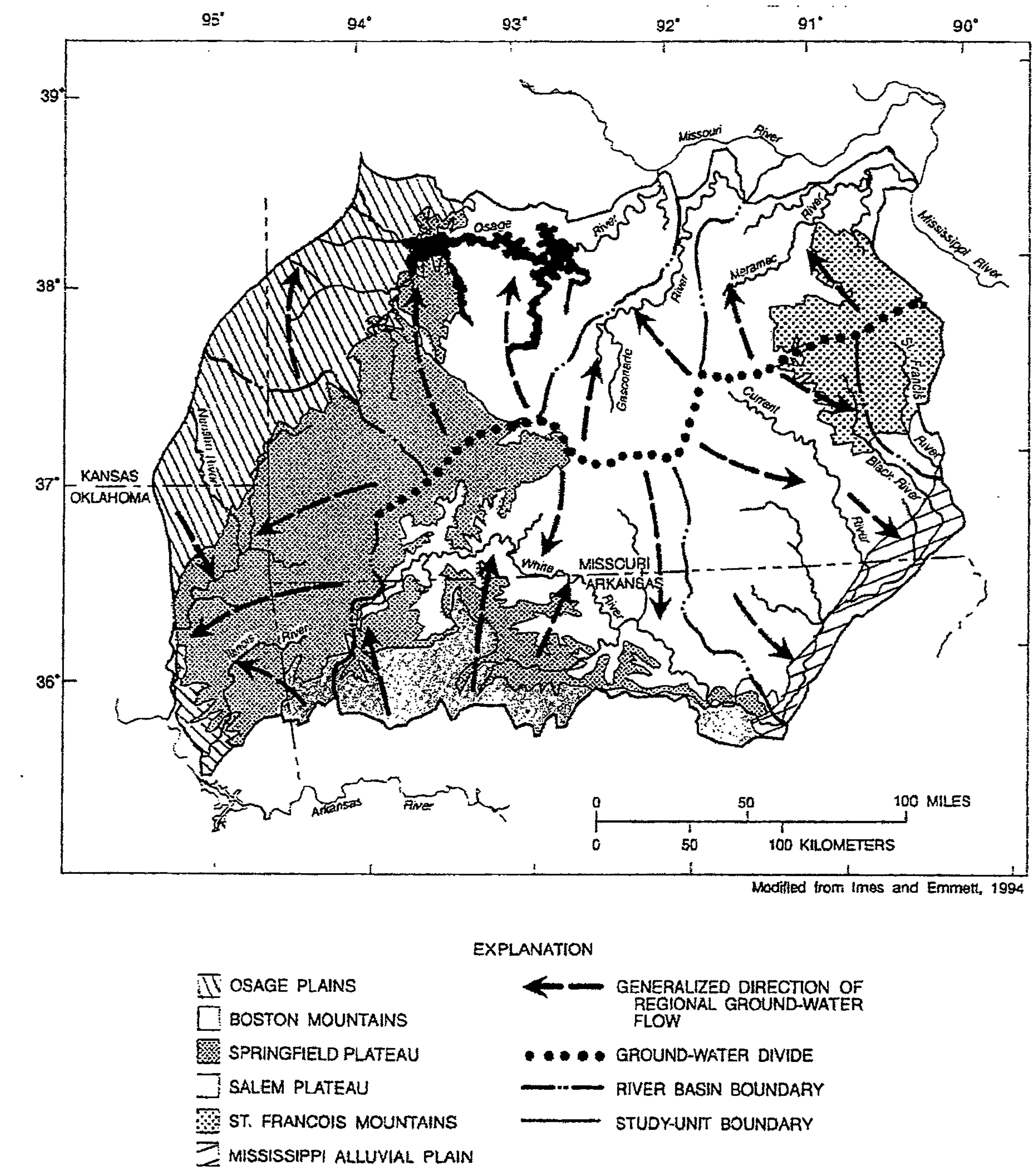
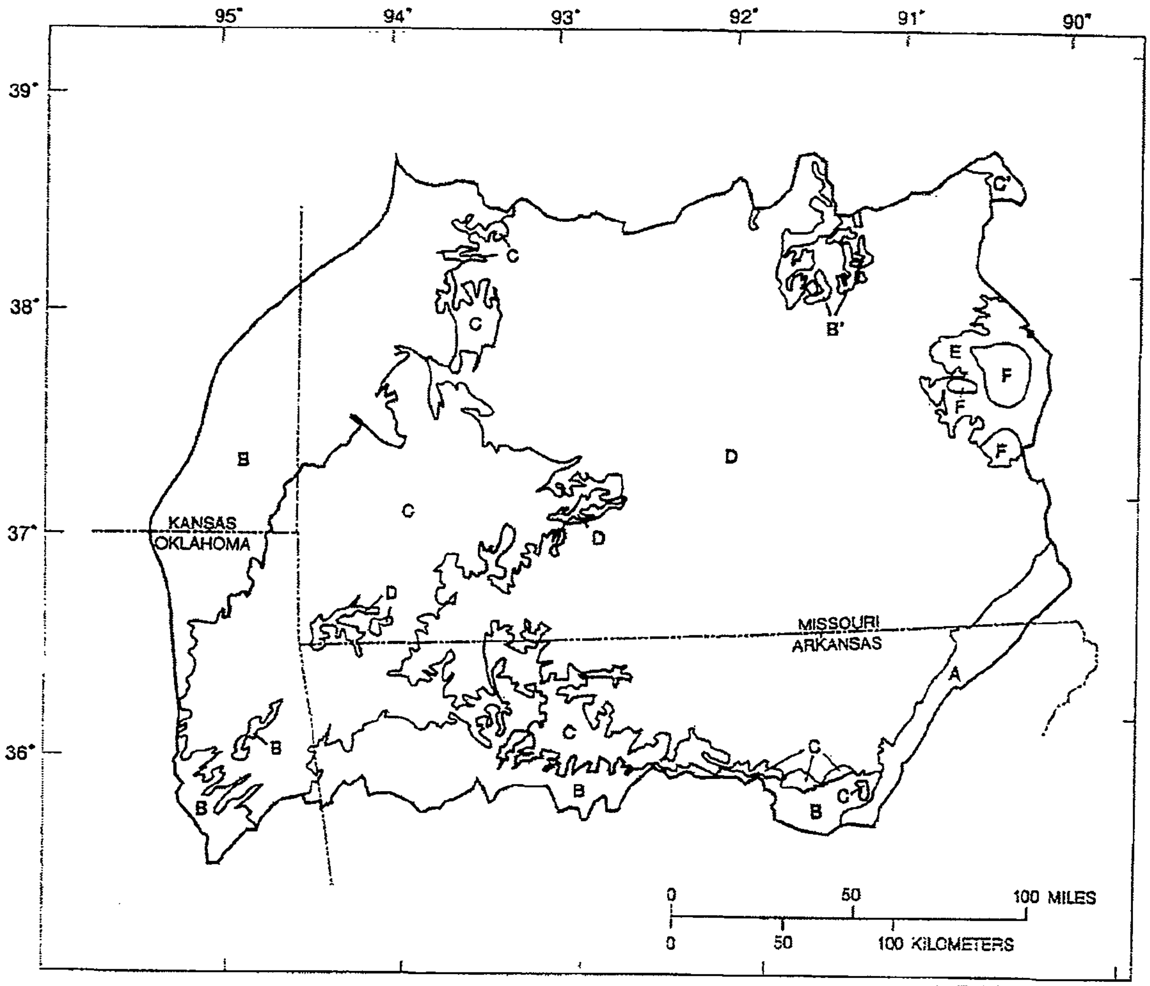


Figure 28. Generalized regional ground-water flow directions in the Ozark Plateaus study unit.

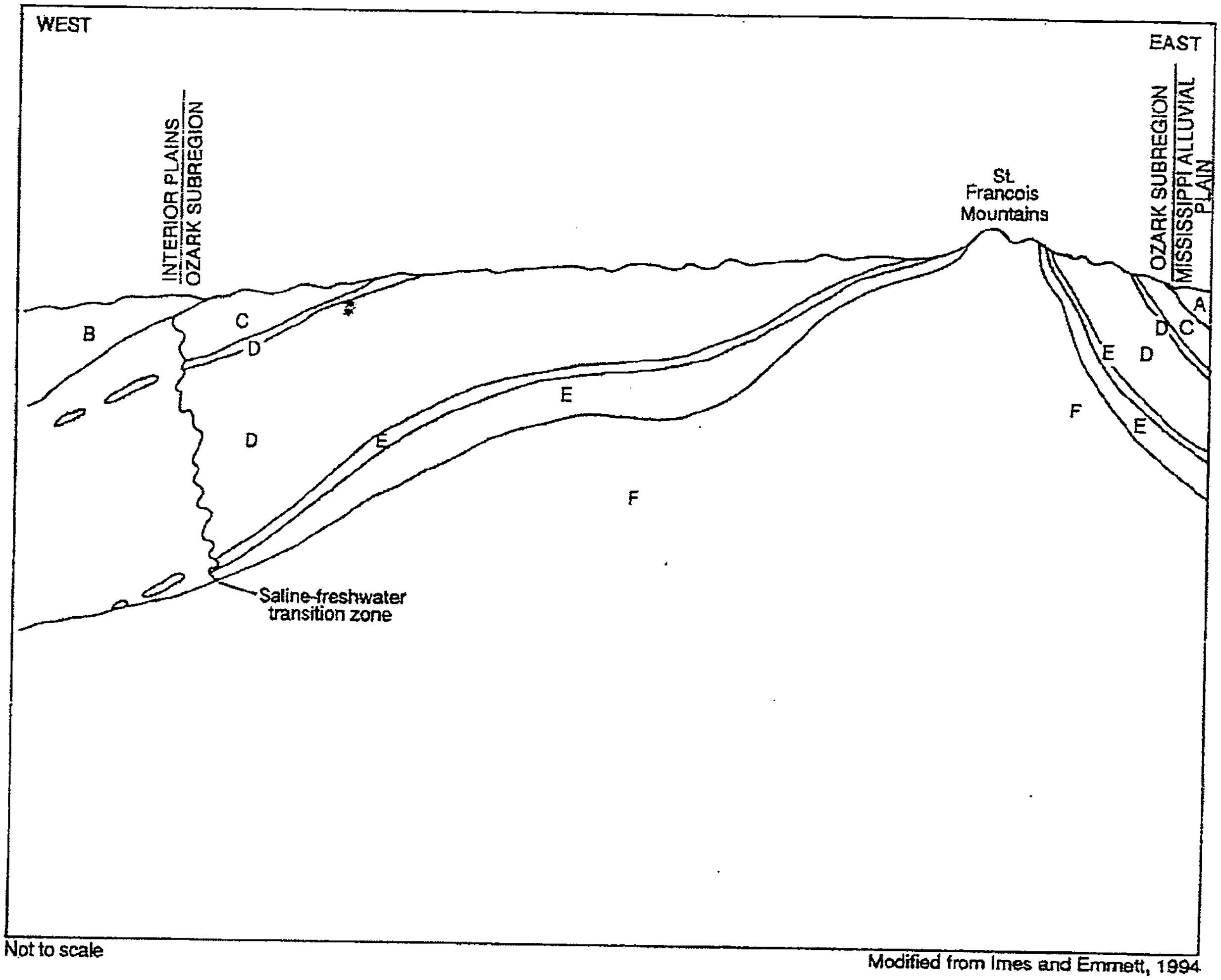


Modified from Imes, 1990a

EXPLANATION

- A — UNCONSOLIDATED SEDIMENTS (MISSISSIPPI ALLUVIAL PLAIN)
- B — WESTERN INTERIOR PLAINS CONFINING SYSTEM
- B' — ROCKS OF PENNSYLVANIAN AGE–Geologically similar to, but hydraulically separate from the Western Interior Plains confining system
- C — SPRINGFIELD PLATEAU AQUIFER
- C' — ROCKS OF MISSISSIPPIAN AGE–Geologically similar to, but hydraulically separate from the Springfield Plateau aquifer
- D — OZARK AQUIFER AND CONFINING UNIT
- E — ST. FRANCOIS AQUIFER AND CONFINING UNIT
- F — BASEMENT CONFINING UNIT
- HYDROGEOLOGIC-UNIT BOUNDARY
- STUDY-UNIT BOUNDARY

Figure 29. Location of hydrogeologic units in the Ozark Plateaus study unit.



EXPLANATION

A UNCONSOLIDATED SEDIMENTS (MISSISSIPPI ALLUVIAL PLAIN)

B WESTERN INTERIOR PLAINS CONFINING SYSTEM

C SPRINGFIELD PLATEAU AQUIFER

D OZARK AQUIFER AND CONFINING UNIT

E ST. FRANCOIS AQUIFER AND CONFINING UNIT

F BASEMENT CONFINING UNIT

Figure 30. Generalized hydrogeologic section showing stratigraphic relations of regional hydrogeologic units in the Ozark Plateaus study unit.

but hydraulically unconnected, rocks are present in the north-central part of the study unit (Imes and Emmett, 1994).

Altitude of the top of the confining system ranges from 800 to 1,000 ft above sea level in the Osage Plains, and from 1,000 to more than 2,000 ft above sea level in the Boston Mountains. The system is from 40 to 800 ft thick in the Osage Plains, but averages between 1,500 and 2,000 ft in thickness in the Boston Mountains (Imes, 1990g).

Lithologies in this regional confining system include relatively permeable sandstone and limestone beds separated by thick layers of impermeable shale that result in an overall low permeability. Hydraulic conductivities generally range from 0.001 to 0.01 ft/d depending upon thickness and shale content (Imes and Emmett, 1994).

Yields of wells in western Missouri range from 1 to 40 gal/min. Specific capacities of these wells range from 0.1 to 3 gal/min/ft (gallons per minute per foot; Kleeschulte and others, 1985). Yields of 16 wells completed in this confining system in northwestern Arkansas range from 2.5 to 19 gal/min (Imes and Emmett, 1994).

Springfield Plateau Aquifer

The Springfield Plateau aquifer, where it is unconfined, coincides with the Springfield Plateau (fig. 29). It consists of limestones and cherty limestones of Mississippian age (fig. 7). In northeastern Oklahoma, the aquifer includes the Moorefield Formation, which elsewhere is shaly. The aquifer is confined by the Western Interior Plains confining system where it underlies the Boston Mountains and Osage Plains (Imes and Emmett, 1994).

Altitude of the top of the aquifer ranges from about 200 ft to 1,600 ft above sea level where the aquifer crops out and is unconfined. Dip of the beds generally is about 11 ft/mi. Thickness of the aquifer ranges from about 100 ft in south-central Missouri to about 400 ft in southeastern Kansas (Imes, 1990f).

The configuration of the potentiometric surface of the unconfined Springfield Plateau aquifer generally reflects the overlying topography. Ground-water levels range from 700 ft above sea level in west-central Missouri to more than 1,400 ft above sea level in southwestern Missouri. The unconfined Springfield Plateau aquifer is recharged nearly everywhere by precipitation. Ground water flows mostly laterally and then discharges in springs and seeps along streams. Where the aquifer is confined, it is recharged by lateral flow from the outcrop areas, and by seepage from the overlying Western Interior Plains confining system (Imes and Emmett, 1994).

Fracturing and dissolutioning of the limestone units in the Springfield Plateau results in karst features, such as sinkholes and caves, and the aquifer is characterized by high secondary porosity and relatively high permeability. Karst features and springs are more abundant in the nonchert-bearing limestones, such as the St. Joe Member of the Boone Formation, than in the chert-bearing limestones.

The Springfield Plateau aquifer is anisotropic and heterogenous, but average horizontal hydraulic conductivity is estimated to be about 22 ft/d. Horizontal hydraulic conductivity is about an order of magnitude greater than vertical hydraulic conductivity. Average transmissivity ranges from about 1,700 to 8,600 ft^2/d and increases with aquifer thickness (Imes and Emmett, 1994).

Wells drilled into the Springfield Plateau aquifer generally have yields of less than 20 gal/min; therefore, most wells are used primarily for domestic water supply and for watering livestock. However, several industrial wells completed in this aquifer in southwestern Missouri yield 300 to 400 gal/min (Imes and Emmett, 1994).

Ozark Confining Unit

The Ozark confining unit consists of rocks of Devonian and Mississippian age from the Chattanooga Shale through the Northview Shale and Chouteau Limestone (fig. 7). The confining unit consists mostly of shales and dense limestones that crop out along the Eureka Springs Escarpment in southwestern Missouri and northwestern Arkansas and underlie much of the Springfield Plateau aquifer (fig. 29). The Ozark confining unit averages about 60 to 80 ft in thickness, but locally is as much as 120 ft thick in southeastern Kansas (Imes, 1990e).

Shales and dense limestones in the Ozark confining unit hydraulically separate the overlying Springfield Plateau aquifer from the underlying Ozark aquifer. Shale content ranges from about 10 to 100 percent in much of northwestern Arkansas. Shale is missing from the unit in parts of southwestern Missouri, northeastern Oklahoma, and southeastern Kansas (Imes, 1990e). Differences in water levels of about 50 ft between the Springfield Plateau and the Ozark aquifers indicate that, even where the shale is missing, low vertical hydraulic conductivity of the dense limestones effectively separates the two hydrogeologic units (Imes and Emmett, 1994).

Ozark Aquifer

The Ozark aquifer, which consists of a thick sequence of dolomites, sandstones, limestones, and shales (fig. 7), crops out in the Salem Plateau in south-central Missouri and northern Arkansas (fig. 29). The highest altitude of the top of the aquifer is about 1,500 ft above sea level in south-central Missouri. Altitudes of the top of the aquifer decrease to 300 ft above sea level near the eastern boundary of the study unit, to about sea level near the western boundary, and to nearly 2,000 ft below sea level near the southern boundary (Imes, 1990d).

Aquifer thickness ranges from about 300 ft in northeastern Oklahoma to nearly 4,000 ft in northern Arkansas. However, aquifer thickness averages between 1,500 and 2,000 ft throughout much of the study unit (Imes, 1990d).

The configuration of the potentiometric surface of the unconfined Ozark aquifer generally mimics the overlying topography. Ground-water levels in wells completed in this aquifer average about 700 to 1,000 ft above sea level over much of the Salem Plateau, but are as much as 1,400 ft above sea level in south-central Missouri (Imes, 1990d). Precipitation recharges the unconfined Ozark aquifer nearly everywhere. Ground water flows mostly laterally from the higher altitudes to points of discharge in springs and seeps along streams. The confined part of the Ozark aquifer is recharged by lateral ground-water flow from the unconfined area, and, in places, by seepage from the overlying confining unit (Imes and Emmett, 1994).

The Ozark aquifer is subdivided into five zones based on lithology and permeability. Stratigraphically, the lowest zone is also the thickest, most permeable, and most areally extensive. The lowermost zone includes the highly permeable Potosi and Gasconade Dolomites and the Roubidoux Formation (fig. 7). The second and third permeable zones above the base of the aquifer include units from the Everton Formation through the Plattin Limestone and the Kimmswick and Fernvale Limestones, respectively. The next highest zone is a local confining unit consisting of the Cason and Sylvan Shales. The uppermost permeable zone includes the Brassfield Limestone through Clifty Limestone and the Callaway Limestone and Sallisaw Formation (Imes and Emmett, 1994).

As with the Springfield Plateau aquifer, fracturing and dissolutioning of the rock units comprising the aquifer have resulted in a high degree of secondary porosity and permeability. Hydraulic properties of the aquifer are anisotropic and heterogeneous, but horizontal hydraulic conductivity commonly ranges from 0.001 to 86 ft/d. Yields of wells tapping most of the units range from 50 to 100 gal/min, but can be as much as 500 or 600 gal/min in the Roubidoux Formation or the Potosi Dolomite (Imes and Emmett, 1994).

Perched aquifers exist locally where permeable layers are interbedded with impermeable layers. Ground water in these perched aquifers overlies the regional aquifer and sometimes flows through separate cave and fracture systems, making it difficult to determine local ground-water flow directions (Imes and Emmett, 1994).

Losing streams are common in areas overlying the Ozark aquifer. These streams are sources of recharge to the ground-water system. Results from ground-water dye-tracing studies indicate that water recharging the aquifer from the losing streams can discharge in springs in adjacent drainage basins. This is possible because, on a local scale, ground-water divides do not always coincide with surface-water divides (Harvey and others, 1983).

Dissolution of rocks resulting in increased secondary porosity is greater in the Ozark aquifer than in the Springfield Plateau aquifer. The rocks of the Ozark aquifer consist primarily of the mineral dolomite and those of the Springfield Plateau aquifer consist primarily of the mineral calcite. Although the dissolution kinetics of dolomite are slower than those of calcite (Hess and White, 1989), the dolomites of the Salem Plateau have dissolved faster than the calcite limestones of the Springfield Plateau, as evidenced by the numerous sinkholes (fig. 6) and losing streams in the Salem Plateau.

Dissolution of the rocks which comprise the Ozark aquifer allows deep circulation of the ground water. In south-central Missouri, municipal wells are from 1,300 to 1,500 ft deep and commonly are cased to depths of 950 to 1,000 ft. Despite the depth of these wells, water in some of the wells becomes turbid after a rainstorm, indicating that surface-recharged water rapidly circulates deep within the aquifer (Harvey, 1980).

St. Francois Confining Unit

The St. Francois confining unit hydraulically separates the Ozark aquifer from the underlying St. Francois aquifer (fig. 7; fig. 30). It consists of shales, siltstones, and dolomites of Late Cambrian age, which crop out around the St. Francois Mountains. The unit dips quaquaversally away from its outcrop area. It attains a maximum thickness of 750 ft in parts of Missouri and northern Arkansas.This confining unit is missing in parts of northwestern Arkansas, west-central Missouri, and northeastern Oklahoma (Imes, 1990c).

Maximum shale content of the unit is about 30 percent in the study unit (Imes, 1990c). In places where shale units are thin or missing, impermeable siltstones and dolomites confine the St. Francois aquifer (Imes and Emmett, 1994).

St. Francois Aquifer

The St. Francois aquifer consists of the Lamotte and Reagan Sandstones and the Bonneterre Dolomite of Late Cambrian age, which crop out in the St. Francois Mountains (fig. 7; fig. 29). These units are used as a ground-water resource where they are unconfined, but are rarely used where overlain by the thicker Ozark aquifer. Thickness of the St. Francois aquifer is as much as 900 ft in Missouri and as much as 500 ft in northern Arkansas. Yields of wells completed in this aquifer commonly range from 100 to 500 gal/min (Imes, 1990b).

Permeability of the aquifer is due somewhat to intergranular porosity (primary porosity) in the loosely cemented sandstones, but is due mostly to secondary porosity in the dolomites as a result of fracturing and dissolutioning. Permeability data are sparse because the aquifer is rarely used, but the few available data indicate that horizontal hydraulic conductivity ranges from 0.1 to 8.6 ft/d. Transmissivity ranges from 8.6 to 860 ft^2/d (Imes and Emmett, 1994).

Basement Confining Unit

The Basement confining unit consists mostly of igneous rocks of Precambrian age, which underlie the study unit and crop out in the core of the St. Francois Mountains (fig. 7; fig. 29). These rocks are locally used as a ground-water resource where they crop out. The igneous rocks are relatively impermeable; however, some secondary permeability is generated from fractures in the rocks. Yields of wells completed in this confining unit are as large as 70 gal/min in some wells, but generally are less than 10 gal/min (Imes and Emmett, 1994).

Water Quality

Differences in ground-water quality exist not only between different aquifers, but also within the same aquifer (table 6). Water type and concentrations of dissolved solids and various chemical constituents can differ among the aquifers, and between confined and unconfined parts of the same aquifer. In general, the predominant water type in the Springfield Plateau, Ozark, and St. Francois aquifers, where they are unconfined, is calcium bicarbonate or calcium magnesium bicarbonate (Imes and Davis, 1990a, b; 1991). Calcium is the dominant cation in the ground water of limestone aquifers, whereas, calcium and magnesium are the dominant cations in the ground water of dolomite aquifers. Bicarbonate generally is the dominant anion in water from all three carbonate aquifers; however, sulfate is the dominant anion in water from these aquifers in some areas (Imes and Davis, 1990a, b; 1991). Where the Springfield Plateau and Ozark aquifers are confined near the western boundary of the study unit the predominant water type in these aquifers generally is sodium chloride. No data are available to indicate the water type of the St. Francois aquifer near the western boundary (Imes and Davis, 1990a). The predominant water type in the Western Interior Plains confining system in the Boston Mountains is calcium sodium bicarbonate (Lamonds, 1972). Water type in the Osage Plains section of this confining system is sodium chloride (Kleeschulte and others, 1985).

Dissolved-solids and chloride concentrations in ground water in the study unit can vary by several orders of magnitude (table 6). In water from the Springfield Plateau and Ozark aquifers, dissolved-solids concentrations generally ranged from 200 to 300 mg/L, and chloride concentrations generally ranged from 5 to 10 mg/L. Concentrations of dissolved solids and chloride in water from these aquifers generally increased where the aquifers are confined, particularly along the western boundary. Dissolved-solids concentrations in ground water in the Western Interior Plains confining system ranged from about 20 to 200 mg/L in the Boston Mountains (Lamonds, 1972) but are much higher in other areas. Ground-water samples from 10 wells com-

Table 6. Water type and typical ranges of selected physical and chemical characteristics of ground water in the Ozark Plateaus study unit

[Water type, cationic and anionic species that each contribute 50 percent or more of total cation or anion concentrations, respectively; mg/L, milligrams per liter; Ca, calcium; Na, sodium; HCO_3, bicarbonate; Cl, chloride; SO_4, sulfate; Mg, magnesium; --, no data; all data from Imes and Davis (1990a; b; 1991) unless otherwise indicated]

Hydrogeologic unit	Water type	pH[1]	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Bicarbonate[2], dissolved (mg/L)	Dissolved solids (mg/L)
Western Interior Plains confining system[3]	$CaNaHCO_3$, NaCl	5.2-8.0	--	--	--	20-30,000
Springfield Plateau aquifer	$CaHCO_3$, $CaSO_4$, NaCl	5.2-8.3	<1-1,000	<1-1,000	110-320	<200-5,000
Ozark aquifer	$CaMgHCO_3$, NaCl	7.0-7.2	<1-1,000	<1-500	166-352	<200-10,000
St. Francois aquifer	$CaMgHCO_3$, $CaSO_4$	--	<5-60	<5-100	--	<100-500

[1]From Adamski (1987), Harvey (1980), and Smith and Steele (1990).
[2] From Feder (1979).
[3] From Kleeschulte and others (1985), Lamonds (1972), and Steele (1983).

pleted in the Osage Plains section of this confining system in west-central Missouri had dissolved-solids concentrations that ranged from 1,000 to 3,000 mg/L (Kleeschulte and others, 1985). The pH of ground water in the study unit ranged from 5.2 to 8.3.

Sulfate concentrations in water in the Springfield Plateau, Ozark, and St. Francois aquifers can vary by several orders of magnitude (table 6), but typically are 5.0 to 20.0 mg/L. The highest sulfate concentrations in ground water in the Springfield Plateau aquifer generally are present in southwestern Missouri and southeastern Kansas. The highest sulfate concentrations in water in the Ozark aquifer generally are in the area just north of the St. Francois Mountains and where the aquifer is confined by shales of Pennsylvanian age (Imes and Davis, 1991). Sulfate concentrations of as much as 120 mg/L were present in water from the Ozark aquifer in southwestern Missouri and southeastern Kansas where the aquifer is confined (Imes and Davis, 1990b). The area of elevated sulfate concentrations in water from the Ozark aquifer approximately coincides with the area of elevated sulfate concentration in water from the Springfield Plateau aquifer and could indicate seepage between the aquifers through the Ozark confining unit.

Elevated nitrate concentrations are present in ground water from the unconfined Springfield Plateau and Ozark aquifers in some areas of the study unit (Harvey, 1980; Harvey and others, 1983; Leidy and Morris, 1990). The geometric means of nitrate concentrations in water from the Springfield Plateau and Ozark aquifers in southern Missouri are about 2.4 and 3.4 mg/L, respectively (Feder, 1979). Nitrate concentrations in water from the Springfield Plateau aquifer where it is unconfined ranged from about 0.01 to 46 mg/L. Nitrate concentrations in water from the Ozark aquifer where it is unconfined ranged from about 0.3 to 14 mg/L (Feder, 1979).

Data indicate that water in parts of the unconfined Springfield Plateau aquifer in northwestern Arkansas contains fecal bacteria. Of 70 water samples collected from wells in this area, analyses indicate that 67 percent contained coliform bacteria in concentrations of 1 colony per 100 mL (milliliters) of sample or greater and 51 percent contained fecal streptococcus bacteria in concentrations of 1 colony per 100 mL of sample or greater (Ogden, 1980).

Radionuclides are present in water from the Ozark aquifer in some areas within the study unit. Gross alpha radioactivity ranged from 1.2 to 7.1 pCi/L (picocuries per liter) in eight water samples collected from the confined Ozark aquifer in southwestern Missouri (Feder, 1979). Gross alpha activity exceeded the U.S. Environmental Protection Agency's MCL for drinking water of 15 pCi/L in 11 of 26 water samples from the Roubidoux Formation (Ozark aquifer) in northeastern Oklahoma. Radium-226 concentrations ranged from 0.5 to 11.0 pCi/L in 58 wells completed in the Ozark aquifer (Imes and Emmett, 1994). The combined radium-226 and -228 activity ranged from 5.1 to 13.9 pCi/L in 18 water samples from public-supply wells in Missouri in 1983, and from 4.9 to 12.8 pCi/L in samples from several public-supply wells in northern Arkansas in 1987-89. Depths of these wells ranged from 250 to more than 1,700 ft below land surface. The MCL for combined radium-226 and -228 is 5 pCi/L (U.S. Environmental Protection Agency, 1988).

FACTORS THAT AFFECT WATER QUALITY

Water quality in the Ozark Plateaus study unit is affected by various environmental factors. Climate, physiography, geology, soil type, population, land use, and water use directly and indirectly affect the water quality of the study unit. Additionally, these factors are not independent. This section will briefly describe how these factors interact to effect a geochemical evolution of the water as it flows in the streams and aquifers of the study unit.

Climate

Several climatic factors interact with physiographic, geologic, land use, and population factors to affect water quality in the Ozark Plateaus study unit. Streamflow is strongly affected by precipitation and evapotranspiration; seasonal patterns in precipitation and evapotranspiration cause seasonal variations in streamflow, which cause seasonal variations in quality of surface water and some ground water. Air temperature affects water temperature, which in turn affects reaeration rates, dissolved oxygen and carbon dioxide equilibria, and biochemical reaction rates.

Concentrations of dissolved and suspended constituents in surface waters vary with flow. Concentrations of dissolved constituents in surface water generally are highest during low flows because of the larger relative contribution of ground water, and lowest during high flows because of dilution. Concentrations of suspended constituents in surface water generally are highest during high flows because of runoff from upland areas and resuspension of stream bottom materials. A large percentage of the annual load of suspended sediment or other constituents can be transported in a stream during one or two high-flow periods.

The water quality in streams differs depending on the amount of point-source contamination entering the stream as well as streamflow conditions. For example, the quality of water in streams that receive point-source contaminant discharges will be most affected during low-flow periods because of lower volumes of streamflow to dilute the wastewater from the point source. Wastes with high biochemical oxygen demands will have the most serious effects during these periods because of reduced reaeration and, usually, high water temperatures in the stream. Stream segments that do not receive point-source wastewater discharges generally will have the highest concentrations of constituents from nonpoint sources during high-flow periods. During these high-flow periods, suspended materials can be transported into the streams where they can settle to the streambed and affect the water quality for long periods of time.

Shallow ground water can be expected to show seasonal patterns in dissolved constituent concentrations because of reduced recharge and longer residence times during periods of dry weather. Springs that are rapidly recharged from precipitation and streamflow can be expected to respond to rainstorms with increased discharge, decreased concentrations of some constituents because of dilution, and elevated concentrations of some constituents (primarily nutrients, bacteria, and suspended materials) because of the movement of these constituents from the surface into the spring system (Steele and others, 1985; Leidy and Morris, 1990).

The chemical quality of precipitation also affects the quality of surface and ground water. Precipitation that is relatively dilute and slightly acidic decreases the dissolved-solids concentration and the pH of surface water, particularly during storms and in areas such as the Boston Mountains where alkalinity is naturally low. Carbonic acid, formed by the reaction of precipitation with carbon dioxide in the atmosphere and soil, also reacts with calcite, resulting in elevated concentrations of calcium and bicarbonate ions. Precipitation contributes a substantial percentage of the sulfate in streamwater, where the natural sulfate concentrations are low and human contributions are small (Smith and Alexander, 1983).

Physiography

Physiography affects water quality to the extent that it controls the volume and intensity of runoff during a rainstorm. In places with steep slopes and rugged topography, such as in the Boston Mountains or the Eureka Springs Escarpment, runoff after a rainstorm is greater as compared to runoff in places with relatively gentle slopes and flat topography. Increased runoff can cause erosion and increased sediment loads in nearby streams. Other surface contaminants are also more likely to be flushed into streams during rainstorms in areas with steep slopes than in areas with gentle slopes.

The karst topography throughout much of the study unit affects ground-water quality. The numerous sinkholes present in the Springfield and Salem Plateaus allow surface water to rapidly infiltrate into the subsurface and recharge the underlying shallow aquifers. Contaminants on the land surface are readily flushed into the aquifer, particularly during rainstorms. The soils that often line the bottom of sinkholes commonly are too thin to remove contaminants from water recharging the aquifer through ion adsorption or filtering (Harvey, 1980).

Geology

Geology affects water quality through physical and geochemical processes. Ground water in the fractures and cave systems in the rocks of the study unit flows faster and generally has less interaction with the rock matrix than water in the intergranular pores spaces of the rocks. Where secondary porosity is substantial, dissolved and particulate contaminants are rapidly transported through the aquifer with minimal removal by adsorption or filtering. Furthermore, fractures and cave systems allow ground water to flow under surface-drainage divides into adjacent drainage basins, which makes determining the contaminant source or direction of migration difficult.

Geochemical processes probably are the most important natural factors that directly affect water quality on a regional scale in the study unit. The minerals and rocks of the region are the source of most dissolved constituents in the water (Harvey, 1980). Even for most streams and rivers, geochemical processes directly affect water quality during periods of low flow, when the ground-water contribution to streamflow is relatively large. These processes include, but are not limited to, mineral dissolution, ion exchange, and oxidation-reduction reactions.

Clearly, the most important of these processes is the dissolution of carbonate minerals, such as calcite and dolomite, which causes the water type over most of the region to be calcium or calcium magnesium bicarbonate. Carbon dioxide, which is present in the atmosphere and forms in the soil from the oxidation of organic matter, mixes with water to form carbonic acid. The acid reacts with (dissolves) calcite to generate calcium and bicarbonate ions. The dissolution forms openings that eventually can develop into cave systems or sinkholes.

Ion exchange along a ground-water flow path can cause the dominant cation to change from calcium or magnesium to sodium (Drever, 1988). Divalent cations such as calcium and magnesium readily exchange for sodium sorbed onto clays in the aquifer media.

Other important geochemical reactions include oxidation and dissolution of sulfide minerals--pyrite, sphalerite, and galena--and uranium-bearing minerals. Dissolution of these minerals increases the trace-element, sulfate, and radionuclide concentrations in the water.

Soils

Water quality is affected by the leaching and runoff potentials of soil, which are a result of physical and chemical properties of the soil. These physical and chemical properties include soil thickness and permeability and ionic adsorption capacity.

A wide range of soil thicknesses and permeabilities is present in the Ozark Plateaus study unit. A thick, low permeability soil, particularly one with a clay fragipan, will prevent leaching and allow runoff. In areas underlain by these soils, contaminants and sediments on the land surface can be flushed into nearby streams, whereas areas underlain by a thin, permeable soil will allow water to readily infiltrate into the ground-water system. Contaminants and sediments on the land surface are less likely to be flushed into streams in areas underlain by these soils but can be transported into the unconfined aquifers.

In general, the ionic adsorption capacity of the alfisols and ultisols of the Ozark Plateaus Province is minimal. Kaolinite, illite, and hydroxide clays, which constitute the soil types of the Ozark Plateaus Province, are relatively low in ionic adsorption capacity compared to expandable clays and organic matter, which constitute the soil types of the Osage Plains (Brady, 1984, p. 170). Hence, ionic constituents in infiltrating water will not be readily adsorbed by most soils in the Ozark Plateaus Province.

Soil particles and ions that are adsorbed onto these particles can, in places where runoff potential is high, be flushed into nearby streams or into the shallow aquifer. For example, potassium, nitrate, and orthophosphate concentrations increased in water samples from three springs in northern Arkansas after a rainstorm (Leidy and Morris, 1990). Concentrations of these constituents probably increased when these ions were desorbed from soil particles that were flushed into the springs.

Population

The distribution of the population within the study unit affects the quality of surface and ground waters. Urban areas, in addition to having larger populations, typically have more industries and produce larger quantities of municipal and industrial wastewater. Industrial areas, residential areas, streets and other paved areas, golf courses, and construction areas are nonpoint sources of nutrients, trace elements, suspended sediments, pesticides, and other synthetic organic compounds to streams draining the area (Missouri Department of Natural Resources, 1990, p. 27, 46-48). In rural areas that are not served by municipal sewers, septic systems can be nonpoint sources of nutrients and bacteria to surface and ground water, if the systems do not adequately treat the wastewater.

Concentrations of nutrients and bacteria in water in the streams and rivers in much of the Springfield Plateau are higher than those in water in the streams in the rest of the study unit (Petersen, 1988; J.C. Petersen, J.V. Davis, and J.F. Kenny, U.S. Geological Survey, written commun., 1991). The largest cities in the study unit and many of the most densely populated nonurban areas are located in the Springfield Plateau. Municipal and industrial wastewater (Missouri Department of Natural Resources, 1990, p. 32) and leachate from septic systems all probably affect water in the Springfield Plateau. However, in Arkansas most streams and rivers that do not support their designated use are considered to be affected primarily by nonpoint sources resulting from agricultural activity (Giese and others, 1990, p. 232, 281, 286) rather than by municipal wastewaters, industrial wastewaters, or septic system leachate. Other concerns for areas in the Springfield Plateau include the effect of increased population, recreation, tourism, and related development upon water quality in the White, Neosho, and Osage River lakes areas.

Land Use

Land use is an important factor that affects the quality of surface and ground water throughout the study unit. Two land uses in the Ozark Plateaus study unit, agriculture and mining, affect water quality over large areas. Agricultural land use, which includes poultry, cattle, and swine production on pastureland, and row crops on cropland, can result in elevated concentrations of ionic constituents, including sodium, potassium, chloride, nitrate, and phosphate, and fecal bacteria in surface and ground water (Feder, 1979; Harvey and others, 1983; Leidy and Morris, 1990). Fertilizers, particularly animal wastes, spread across pasture and cropland in the study unit are a major source of these ions and bacteria. Production of large numbers of poultry, cattle, and swine in northwestern Arkansas, and increasingly in southwestern Missouri and northeastern Oklahoma, is contributing to elevated nutrient and bacteria concentrations in streams (Giese and others, 1990; Missouri Department of Natural Resources, 1990; Kurklin and Jennings, 1993). Some of the highest nutrient and fecal-coliform bacteria concentrations in surface water in Arkansas are present in this area (Petersen, 1988). Concerns about existing or potential animal-waste problems have prompted studies in a number of areas, including Boone County, Arkansas (Leidy and Morris, 1990), the Buffalo River Basin (Mott, 1991; Mott and Steele, 1991), and the Niangua River Basin (Harvey and others, 1983).

Substantial amounts of soybeans, sorghum, corn, and wheat are produced within the study unit in the Osage Plains and the Mississippi Alluvial Plain. Substantial amounts of rice also are produced in the Mississippi Alluvial Plain. Past and potential future application of fertilizers and pesticides to these crops could affect water quality in these areas.

Mining activities increase the dissolution rate of sulfide minerals by exposing the minerals to oxidizing conditions. The dissolution of sulfide minerals results in decreased pH and increased suspended sediment and concentrations of dissolved solids, sulfate, and trace elements in the surface and ground water of the study unit.

Surface coal-mining activities in the Spring River Basin, Osage River Basin, and the Lightning and Cherry Creek Basins (small tributaries to the Neosho River in Kansas) have adversely affected water quality, principally by causing elevated concentrations of dissolved solids, sulfate, iron, and manganese in waters draining the mined areas (Bevans and others, 1984; Marcher and others, 1984). In places, mining activity could be the cause of sulfate being the dominant anion in ground water (Imes and Davis, 1990a, b; 1991).

Lead, zinc, and barite mining activities have affected water quality in several areas. Water quality in the Tar Creek Basin (a small tributary to the Neosho River in Oklahoma) and the Spring River Basin has been adversely affected by lead-zinc mining activities (Parkhurst, 1987; Spruill, 1987; Davis and Schumacher, 1992). Discharges from flooded underground lead-zinc mines and runoff from tailings piles contribute large amounts of calcium, sulfate, dissolved solids, and zinc to receiving streams.

The Big River Basin encompasses much of the Old Lead Belt mining area and much of the area of past and present barite mining. About 15 mi of streams in the basin do not support or only partially support the designated beneficial uses because of mining activities (Missouri Department of Natural Resources, 1990). The potential failure of tailings pond dams also is of concern (Missouri Department of Natural Resources, 1984). In the Viburnum Trend, inactive iron, lead-zinc, and barite mines are located in the upper Meramec River Basin. Lead and zinc ores are actively mined, milled, and smelted in the upper Meramec River, upper Black River, and upper St. Francis River Basins. Local water-quality problems and concerns regarding potential failure of tailings pond dams and trace-element deposition in Clearwater Lake have resulted from these mining activities (Missouri Department of Natural Resources, 1984; Smith, 1988).

Water Use

Water use also affects water quality. The quality of the water can be impaired by some uses; consumptive uses can reduce the volume of water available for dilution of wastewaters, and some uses, such as reservoir storage and releases, can change natural streamflow characteristics that can affect water quality.

Some water uses can impair the quality of water. For example, water that is withdrawn for public supply systems, used for domestic uses, and then discharged from wastewater-treatment plants often will contain elevated concentrations of nutrients, dissolved solids, suspended solids, and trace elements (Hem, 1989). Similarly, industrial, agricultural, mining, or aquacultural uses of water can impair the quality of water.

The withdrawal of water from a stream or aquifer reduces the volume of water in that stream or aquifer. Withdrawal of water from streams can reduce the amount of water available for dilution, lower water velocities and depths, and reduce reaeration. In aquifers, substantial withdrawals of water can change the direction of water movement and induce the encroachment of water with impaired quality. For example, groundwater withdrawals from areas in the northwestern part of the study unit along the transition zone between freshwater and saline water have caused declines in water levels. The declines have resulted in the eastward encroachment of saline ground water into freshwater areas (Kleeschulte and others, 1985).

Dams substantially alter the downstream water quality. Chemical and physical characteristics of the stream, such as water temperature and concentrations of dissolved oxygen, suspended sediment, nutrients, and trace elements, commonly are altered (for examples see Walburg and others, 1981). The direction and magnitude of this alteration is dependent on factors such as reservoir size, reservoir release depth, and season. The volume of water released also affects water quality; for example, low release volumes can decrease dilution, velocity, depth, and reaeration. High release volumes can resuspend streambed materials.

SUMMARY

The Ozark Plateaus study is 1 of 20 National Water-Quality Assessment (NAWQA) studies initiated by the U.S. Geological Survey in 1991. When the NAWQA program is fully implemented, a total of 60 study units in the United States will be investigated on a rotational basis. Study-unit investigations will include 5 years of intensive assessment activity followed by 5 years of low-level monitoring.

The Ozark Plateaus study unit has an area of approximately 48,000 mi^2 and includes parts of Arkansas, Kansas, Missouri, and Oklahoma. Major water-quality concerns in the study unit include elevated concentrations of nutrients in surface and ground waters; elevated concentrations of bacteria, trace elements, dissolved solids, and radionuclides in ground water, and saline ground-water encroachment.

The study unit has a temperate climate with average annual precipitation ranging from about 38 to 48 in., and mean annual air temperature ranging from 56 to 60 °F. Evapotranspiration rates range from 30 to 35 in/yr.

The study unit contains most of the Ozark Plateaus Province and parts of the adjacent Osage Plains section of the Central Lowland Province and Mississippi Alluvial Plain section of the Coastal Plain Province. The Ozark Plateaus Province consists of three sections--the Springfield Plateau, the Salem Plateau, and the Boston Mountains. Topography in the study unit is mostly gently rolling, except in the Boston Mountains and along the escarpment separating the Springfield and Salem Plateaus, where it is rugged. Land-surface altitudes range from just over 200 ft to more than 2,300 ft above sea level with local relief of as much as 1,000 ft. Karst features such as sinkholes and caves are common in the Springfield Plateau and abundant in the Salem Plateau. Springs are abundant and several large springs (discharge greater than 100 ft^3/s) are located in the Salem Plateau.

Basement igneous rocks of Precambrian age crop out in the St. Francois Mountains in southeastern Missouri. These basement rocks are overlain by as much as 5,000 ft of gently dipping younger sedimentary rocks throughout much of the study unit. Dip of the sedimentary rocks is greatest to the east-southeast relative to other directions. The igneous rocks include granite, rhyolite, and diabase. The sedimentary rocks include rocks of Cambrian through Ordovician age, which consist of dolomite, sandstone, and limestone with minor amounts of shale; rocks of Mississippian age, which consist mostly of cherty limestones; and rocks of Pennsylvanian age, which consist mostly of shale, sandstone, and limestone. In some areas, rocks of Cambrian through Mississippian age contain commercially important deposits of lead and zinc minerals. Also, rocks of Pennsylvanian age contain coal deposits in some parts of the study unit. The igneous and sedimentary rocks underlying the study unit have been extensively fractured and faulted.

Alfisol and ultisol soil types underlie most of the study unit. These soils are moderately to deeply weathered and have a wide range of hydraulic properties. Mollisols, which underlie most of the Osage Plains, contain more organic matter and expandable clays than alfisols or ultisols and are not as weathered.

Population in the study unit was approximately 2.3 million people in 1990 and increased 28 percent between 1970 and 1990. Northwestern Arkansas and southwestern Missouri are the fastest growing areas in the study unit. Springfield, Missouri, with a 1990 population of 140,494, is the largest city in the study unit.

Land use in the study unit is predominantly pasture and cropland in the northwestern part of the study unit, and forest and pasture in the southeastern part. Forests consist mostly of oak and hickory trees mixed with some pine trees. Pasture is mostly fescue and Kentucky blue grass. Poultry farming is a major industry in the southwestern part of the study unit. Mining, primarily in the four major lead-zinc mining districts, has been an important part of the local economy in the past. Coal has also been mined in the northwestern part of the study unit.

Total water use averaged 1,053 Mgal/d in the study unit in 1990. Approximately 58 percent was withdrawn from ground-water sources and 42 percent from surface-water sources. Ground-water use for irrigation accounted for 39 percent and surface-water use for public supply accounted for 20 percent of total withdrawals. The surface-water use was primarily from the reservoirs in northwestern Arkansas and southwestern Missouri; ground-water use was mostly for rice production in the southeastern part of the study unit.

All or part of seven major river basins are located within the study unit. These basins include the White, Neosho-Illinois, Osage, Gasconade, Meramec, St. Francis, and Black River Basins. Many of the rivers have been impounded to form reservoirs. The White River Basin alone has five major reservoirs. Several of the rivers have been designated for protection from future development. The Buffalo River has been designated as the Buffalo National River; and the Current, Eleven Point, and Jacks Fork Rivers have been designated as National Scenic Rivers. The Illinois River is designated as a scenic river by the State of Oklahoma.

Stream gradients are steepest in the Boston and St. Francois Mountains and least in the Osage Plains and Mississippi Alluvial Plain. Streambed material ranges from clay and silt in the Osage Plains to sand, gravel, boulders, and bedrock in most of the Ozark Plateaus Province. Streams in the Osage Plains are turbid, with long pools separated by poorly defined riffles. Streams in the Ozarks Plateaus Province are mostly clear, with pools separated by riffles, and in places, cascading waterfalls.

Mean annual runoff ranges from 9 to 10 in. in the Osage Plains to 14 to 20 in. in the Boston Mountains. Minimum monthly streamflows generally occur from July through October, and maximum monthly streamflows occur from March through May. Surface- and ground-water interactions are greatest in the Springfield and Salem Plateaus and least in the Boston Mountains and Osage Plains. Ground water discharging through springs contributes significantly to low flows in the Springfield and Salem Plateaus.

Surface water in the study unit generally is a calcium or calcium magnesium bicarbonate type water. Dissolved-solids concentrations in water from streams ranged from about 40 mg/L in the Boston Mountains to as much as 280 mg/L in the Osage Plains, but generally were less than 200 mg/L. Streams in the Boston Mountains generally are the least mineralized and those in the Osage Plains generally are the most mineralized in the study unit.

The study unit is divided into seven hydrogeologic units consisting of three major aquifers interbedded with four confining units. These units, from youngest to oldest, are as follows: the Western Interior Plains confining system, the Springfield Plateau aquifer, the Ozark confining unit, the Ozark aquifer, the St. Francois confining unit, the St. Francois aquifer, and the Basement confining unit. The unconsolidated sediments of the Mississippi Alluvial Plain, which constitute a productive aquifer in a small part of the study unit, are not discussed in this report.

The Western Interior Plains confining system consists of relatively permeable sandstone and limestone beds separated by thick layers of impermeable shales. The system is used locally as a source of water for domestic supplies. Overall, the confining system has low permeability and well yields generally are less than 40 gal/min.

The Springfield Plateau and Ozark aquifers are formed from thick sequences of limestones and dolomites that have secondary porosity as a result of fracturing and dissolutioning. Where the Springfield Plateau aquifer is unconfined, it is extensively used as a source of domestic water. Yields of wells completed in this aquifer generally are less than 20 gal/min. The Ozark aquifer is used throughout much of the area for public supply and domestic use. Well yields commonly range from 50 to 100 gal/min but are as much as 600 gal/min in some areas.

The St. Francois aquifer consists of sandstones and dolomites of Cambrian age. Well yields in the aquifer can be as much as 500 gal/min. The aquifer is little used except where it crops out.

The Ozark and St. Francois confining units consist mostly of shales and dense limestones or dolomites. These confining units hydraulically separate the overlying and underlying aquifers. The Basement confining unit underlies the study unit and consists of mostly igneous rocks.

Ground water in most of the aquifers in the study unit is a calcium or calcium magnesium bicarbonate type water, but locally it can be calcium sulfate or sodium chloride water where the aquifers are confined. Dissolved-solids concentrations generally ranged from 200 to 300 mg/L, but can be as much as 10,000 mg/L where the aquifers are confined along the western boundary. The pH of ground water in the study unit ranged from 5.2 to 8.3. The Springfield Plateau aquifer locally can contain fecal bacteria. The Ozark aquifer has elevated concentrations of radionuclides in some areas where it is confined. Elevated nitrate concentrations are present in ground water from unconfined parts of the Springfield Plateau and Ozark aquifer in some areas.

Factors that affect water quality in the study unit include climate, physiography, geology, soils, population, land use, and water use. The geochemical processes of mineral dissolution, ion exchange, and oxidation-reduction reactions are the dominant natural factors affecting water quality on a regional scale. Land use and population density can affect the potential for the introduction of contaminants into the water from human sources. Agricultural and mining land-use activities can increase the concentrations of nutrients, bacteria, dissolved solids, sulfate, and trace elements in surface and ground water. The population density can affect point and non-point sources of nutrients, trace elements, suspended sediment, and organic compounds in runoff and wastewater discharges. Climate, physiography, soils, and water use affect water quality by affecting the quantity and movement of water in the study unit.

REFERENCES

Ackerman, D.J., 1989, Hydrology of the Mississippi River Valley alluvial aquifer, south-central United States--A preliminary assessment of the regional flow system: U.S. Geological Survey Water-Resources Investigations Report 88-4028, 74 p.

Adamski, J.C., 1987, The effect of agriculture on the quality of ground water in a karstified carbonate terrain, northwest Arkansas: Fayetteville, University of Arkansas, unpublished M.S. thesis, 124 p.

Albin, D.R., Hines, M.S., and Stephens, J.W., 1967, Water resources of Jackson and Independence Counties, Arkansas: U.S. Geological Survey Water-Supply Paper 1839-G, 29 p.

Allgood, F.P., and Persinger, I.D., 1979, Missouri general soil map and soil association descriptions: U.S. Soil Conservation Service, 73 p.

Anderson, R.K., and Wells, J.S., 1967, Oil and gas, *in* Mineral and water resources of Missouri: Rolla, Missouri Division of Geology and Land Survey, v. 43, p. 243-252.

Barks, J.H., 1978, Water quality in the Ozark National Scenic Riverways, Missouri: U.S. Geological Survey Water-Supply Paper 2048, 57 p.

Bennett, Chuck, Giese, John, Keith, Bill, McDaniel, Roland, Maner, Martin, O'Shaughnessy, Niall, and Singleton, Bob, 1987, Physical, chemical, and biological characteristics of least-disturbed reference streams in Arkansas' ecoregions--volume I, Data compilation: Little Rock, Arkansas Department of Pollution Control and Ecology, 685 p.

Bevans, H.E., Skelton, John, Kenny, J.F., and Davis, J.V., 1984, Hydrology of Area 39, Western Region, Interior Coal Province, Kansas and Missouri: U.S. Geological Survey Water-Resources Investigations Open-File Report 83-851, 83 p.

Beveridge, T.R., and Vineyard, J.D. (ed.), 1990, Geologic wonders and curiosities of Missouri: Rolla, Missouri Division of Geology and Land Survey Educational Series 4, 391 p.

Brady, N.C., 1984, The nature and properties of soils (9 ed): New York, Macmillan, 750 p.

Bureau of Outdoor Recreation, 1973, The Gasconade River--A summary of the Federal-State team findings: Ann Arbor, Michigan, Bureau of Outdoor Recreation, Lake Central Region, 25 p.

Caplan, W.M., 1957, Subsurface geology of northwestern Arkansas: Little Rock, Arkansas Geological and Conservation Commission Information Circular 19, 14 p.

_____ 1960, Subsurface geology of Pre-Everton rocks in northern Arkansas: Little Rock, Arkansas Geological and Conservation Commission Information Circular 21, 17 p.

Christenson, S.C., Parkhurst, D.L., and Fairchild, R.W., 1990, Geohydrology and water quality of the Roubidoux aquifer, northeastern Oklahoma: U.S. Geological Survey Open-File Report 90-570, 110 p.

Coveney, R.M., Hilpman, P.L., Allen, A.V., and Glascock, M.D., 1987, Radionuclides in Pennsylvanian black shales of the Midwestern United States, *in* Marikos, M.A., and Hansman, R.H., Geologic causes of natural radionuclide anomalies: Rolla, Missouri Division of Geology and Land Survey Special Publication 4, p. 25-42.

Croneis, C., 1930, Geology of the Arkansas Paleozoic area with reference to oil and gas possibilities: Little Rock, Arkansas Geological Survey, 457 p.

Davis, J.V., and Howland, J.R., 1993, Missouri stream water quality, *in* National Water Summary 1990-91--Stream Water Quality: U.S. Geological Survey Water-Supply Paper 2400, p. 351-360.

Davis, J.V., and Schumacher, J.G., 1992, Water-quality characterization of the Spring River basin, southwestern Missouri and southeastern Kansas: U.S. Geological Survey Water-Resources Investigations Report 90-4176, 112 p.

Drever, J.I., 1988, The geochemistry of natural water (2d ed.): Englewood Cliffs, New Jersey, Prentice Hall, 437 p.

Duchrow, R.M., 1984, Water quality survey of the Osage River system, 1975-76: Jefferson City, Missouri Department of Conservation, 356 p.

Dugan, J.T., and Peckenpaugh, J.M., 1985, Effects of climate, vegetation, and soils on consumptive water use and ground-water recharge to the Central Midwest Regional Aquifer System, Mid-Continent United States: U.S. Geological Survey Water-Resources Investigations Report 85-4236, 77 p.

Feder, G.L., 1979, Geochemical survey of waters of Missouri: U.S. Geological Survey Professional Paper 954-E, 78 p.

Fenneman, N.M., 1938, Physiography of eastern United States: New York, McGraw-Hill Book Co., Inc., 714 p.

Fowlkes, D.H., McCright, R.T., and Lowrance, J.S., 1988, Soil survey of Newton County, Arkansas: U.S. Soil Conservation Service, 188 p.

Freiwald, D.A., 1985, Average annual precipitation and runoff for Arkansas, 1951-80: U.S. Geological Survey Water-Resources Investigations Report 84-4363, 1 sheet, scale 1:1,000,000.

_____ 1987, Streamflow gain and loss of selected streams in northern Arkansas: U.S. Geological Survey Water-Resources Investigations Report 86-4185, 4 sheets.

Freiwald, D.A., 1991, National Water-Quality Assessment program--Ozark Plateaus: U.S. Geological Survey Open-File Report 91-162, 1 sheet.

Frezon, S.E., and Glick, E.E., 1959, Pre-Atoka rocks of northern Arkansas: U.S. Geological Survey Professional Paper 314-H, 18 p.

Gann, E.E., Harvey, E.J., Barks, J.H., Fuller, D.L., and Miller, D.E., 1974, Water resources of west-central Missouri: U.S. Geological Survey Hydrologic Investigations Atlas HA-491, 4 sheets.

Gann, E.E., Harvey, E.J., and Miller, D.E., 1976, Water resources of south-central Missouri: U.S. Geological Survey Hydrologic Investigations Atlas HA-550, 4 sheets.

Gebert, W.A., Graczyk, D.J., and Krug, W.R., 1987, Average annual runoff in the United States, 1951-80: U.S. Geological Survey Hydrologic Investigations Atlas HA-710, scale 1:7,500,000.

Giese, John, Keith, Bill, Maner, Martin, McDaniel, Roland, and Singleton, Bob, 1987, Physical, chemical, and biological characteristics of least-disturbed reference streams in Arkansas' ecoregions--Volume II, Data analysis: Little Rock, Arkansas Department of Pollution Control and Ecology, 148 p.

Giese, John, Bennett, Chuck, Keith, Bill, Drown, Steve, Desmarais, Ralph, McDaniel, Roland, Price, Alan, Jones, Lamar, 1990, Arkansas water quality inventory report 1990: Little Rock, Arkansas Department of Pollution Control and Ecology, 353 p.

Gray, Fenton, 1959, Soil map of Oklahoma: U.S. Soil Conservation Service, 1 sheet, scale 1:1,584,000.

Hanson, R.L., 1991, Hydrology of floods and droughts, evapotranspiration and droughts, *in* National Water Summary 1988-89--Floods and Droughts: U.S. Geological Survey Water-Supply Paper 2375, p. 99-104.

Harper, M.D., Fowlkes, D.H., and Howard, D.A., 1981, Soil survey of Boone County, Arkansas: U.S. Soil Conservation Service, 109 p.

Harvey, E.J., 1980, Ground water in the Springfield-Salem Plateaus of southern Missouri and northern Arkansas: U.S. Geological Survey Water-Resources Investigations 80-101, 66 p.

Harvey, E.J., Skelton, John, and Miller, D.E., 1983, Hydrology of carbonate terrane--Niangua, Osage Fork, and Grandglaize Basins, Missouri: Rolla, Missouri Division of Geology and Land Survey Water Resources Report 35, 132 p.

Hauth, L.D., 1974, Technique for estimating the magnitude and frequency of Missouri floods: U.S. Geological Survey Open-File Report, 20 p.

Hayes, W.C., 1961, Guidebook to the geology of the St. Francois Mountain area: Missouri Division of Geological Survey and Water Resources Report of Investigations 26, 137 p.

Hedman, E.R., Skelton, John, and Freiwald, D.A., 1987, Flow characteristics for selected springs and streams in the Ozark subregion, Arkansas, Kansas, Missouri, and Oklahoma: U.S. Geological Survey Hydrologic Investigations Atlas HA-688, 4 sheets, scale 1:500,000.

Hem, J.D., 1989, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hess, J.W., and White, W.B., 1989, Chemical hydrology, *in* White, W.B., and White, E.L. eds., Karst hydrology concepts from the Mammoth Cave area: New York, Van Nostrand Reinhold, p. 145-174.

Hirsch, R.M., Alley, W.M., and Wilber, W.G., 1988, Concepts for a National Water-Quality Assessment program: U.S. Geological Survey Circular 1021, 42 p.

Homyk, Anthony, and Jeffery, H.G., 1967, Water resources investigations--Surface water, *in* Mineral and water resources of Missouri: Rolla, Missouri Division of Geology and Land Survey, v. 43, p. 258-281.

Howe, W.B., and Koenig, J.W., 1961, Stratigraphic succession in Missouri: Rolla, Missouri Division of Geology and Land Survey, v. 40, 185 p.

Howe, W.B., Kurtz, V.E., and Anderson, K.H., 1972, Correlation of Cambrian strata of the Ozarks and upper Mississippi Valley regions: Rolla, Missouri Division of Geology and Land Survey Report of Investigations 52, 60 p.

Hunrichs, R.A., 1983, Identification and classification of perennial streams of Arkansas: U.S. Geological Survey Water-Resources Investigations Report 83-4063, 1 sheet, scale 1:500,000.

Imes, J.L., 1990a, Major geohydrologic units in and adjacent to the Ozarks Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-A, 1 sheet, scale 1:750,000.

_____ 1990b, Major geohydrologic units in and adjacent to the Ozarks Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma--St. Francois aquifer: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-C, 2 sheets, scale 1:750,000.

_____ 1990c, Major geohydrologic units in and adjacent to the Ozarks Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma--St. Francois confining unit: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-D, 3 sheets, scale 1:750,000.

_____ 1990d, Major geohydrologic units in and adjacent to the Ozarks Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma--Ozark aquifer: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-E, 3 sheets, scale 1:750,000.

_____ 1990e, Major geohydrologic units in and adjacent to the Ozarks Plateaus Province, Missouri, Arkansas,

Kansas, and Oklahoma--Ozark confining unit: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-F, 3 sheets, scale 1:750,000.

Imes, J.L., 1990f, Major geohydrologic units in and adjacent to the Ozarks Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma--Springfield aquifer: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-G, 3 sheets, scale 1:750,000.

_____ 1990g, Major geohydrologic units in and adjacent to the Ozarks Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma--Western Interior Plains confining system: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-H, 3 sheets, scale 1:750,000.

Imes, J.L., and Davis, J.V., 1990a, Water type and concentration of dissolved solids, chloride, and sulfate in water from the St. Francois aquifer in Missouri, Arkansas, Kansas, and Oklahoma: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-J, 1 sheet, scale 1:750,000.

_____ 1990b, Water type and concentration of dissolved solids, chloride, and sulfate in water from the Springfield Plateau aquifer in Missouri, Arkansas, Kansas, and Oklahoma: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-L, 2 sheets, scale 1:750,000.

_____ 1991, Water type and concentration of dissolved solids, chloride, and sulfate in water from the Ozark aquifer in Missouri, Arkansas, Kansas, and Oklahoma: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-K, 4 sheets, scale 1:750,000.

Imes, J.L., and Emmett, L.F., 1994, Geohydrology of the Ozark Plateaus aquifer system in parts of Missouri, Arkansas, Oklahoma, and Kansas: U.S. Geological Survey Professional Paper 1414-D, 127 p.

Imes, J.L., and Smith, B.J., 1990, Areal extent, stratigraphic relation, and geohydrologic properties of regional geohydrologic units in southern Missouri: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-I, 3 sheets, scale 1:750,000.

Jordan, P.R., and Irza, T.J., 1975, Magnitude and frequency of floods in Kansas--Unregulated streams: Kansas Water Resources Board Technical Report No. 11, 34 p.

Jorgensen, D.G., and Signor, D.C., 1981, Plan of study for the Central Midwest Regional Aquifer System Analysis in parts of Arkansas, Colorado, Kansas, Missouri, Nebraska, New Mexico, Oklahoma, South Dakota, and Texas: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-206, 28 p.

Kenny, J.R., and Snethen, D.H., 1993, Kansas stream water quality, *in* National Water Summary 1990-91--Stream Water Quality: U.S. Geological Survey Water-Supply Paper 2400, p. 277-284.

Kiilsgaard, T.H., Hayes, W.C., and Heyl, A.V., 1967, Lead and zinc, *in* Mineral and water resources of Missouri: Rolla, Missouri Division of Geology and Land Survey, v. 43, p. 41-63.

Kisvarsanyi, E.B., 1981, Geology of the Precambrian St. Francois terrane, southeastern Missouri: Rolla, Missouri Division of Geology and Land Survey Report of Investigations 64, 58 p.

_____ 1987, southeastern Missouri, *in* Marikos, M.A., and Hansman, R.H., eds., Geologic causes of natural radionuclide anomalies: Rolla, Missouri Division of Geology and Land Survey Special Publication 4, p. 5-15.

Kleeschulte, M.J., Mesko, T.O., and Vandike, J.E., 1985, Appraisal of the groundwater resources of Barton, Vernon, and Bates Counties, Missouri: Rolla, Missouri Division of Geology and Land Survey Water Resources Report 36, 74 p.

Kurklin, J.K., and Jennings, David, 1993, Oklahoma stream water quality, *in* National Water Summary 1990-91--Stream Water Quality: U.S. Geological Survey Water-Supply Paper 2400, p. 445-454.

Lamonds, A.G., 1972, Water-resources reconnaissance of the Ozark Plateaus Province, northern Arkansas: U.S. Geological Survey Hydrologic Investigations Atlas HA-383, 2 sheets.

Lamonds, A.G., Hines, M.S., and Plebuch, R.O., 1969, Water resources of Randolph and Lawrence Counties, Arkansas: U.S. Geological Survey Water-Supply Paper 1879-B, 45 p.

Leahy, P.P., Rosenshein, J.S., and Knopman, D.S., 1990, Implementation plan for the National Water-Quality Assessment program: U.S. Geological Survey Open-File Report 90-174, 10 p.

Leidy, V.A., and Morris, E.E., 1990, Hydrogeology and quality of ground water in the Boone Formation and Cotter Dolomite in karst terrain of northwestern Boone County, Arkansas: U.S. Geological Survey Water-Resources Investigations Report 90-4066, 57 p.

MacDonald, H.C., Zachry, D.L., and Jeffus, Hugh, 1975, Northern Arkansas groundwater inventory: Arkansas Water Resources Research Center Miscellaneous Publication 26, 186 p.

Marcher, M.V., Kenny, J.F., and others, 1984, Hydrology of Area 40, Western Region, Interior Coal Province, Kansas, Oklahoma, and Missouri: U.S. Geological Survey Water-Resources Investigations Open-File Report 83-266, 97 p.

McCracken, M.H., 1967, Structure, *in* Mineral and water resources of Missouri: Rolla, Missouri Division of Geology and Land Survey, v. 43, p. 20-21.

McCracken, M.H., 1971, Structural features of Missouri: Rolla, Missouri Division of Geology and Land Survey Report of Investigations 49, 99 p.

McFarland, J.D., Bush, W.V., Wise, O.A., and Holbrook, Drew, 1979, A guidebook to the Ordovician-Mississippian rocks of north-central Arkansas: Arkansas Geological Commission GB-79-1, 25 p.

Missouri Department of Natural Resources, 1980, Missouri--the Cave State: Rolla, Missouri Division of Geology and Land Survey Fact Sheet 15, 2 p.

_____ 1984, Missouri water quality basin plans, v. 4-8: Jefferson City, Division of Environmental Quality.

_____ 1990, Missouri water quality report: Missouri Department of Natural Resources Water Pollution Control Program, 71 p.

Mott, D.N., 1991, Water quality report, 1985-1990, Buffalo National River: National Park Service, 160 p.

Mott, D.N., and Steele, K.F., 1991, Effects of pasture runoff on water chemistry, Buffalo National River, USA, *in* Peters, N.E., and Walling, D.E., eds., Sediment and stream water quality in a changing environment: Trends and explanation, 20th, Vienna, Austria, 1991, Proceedings, General Assembly of the International Union of Geodesy and Geophysics, p. 229-238.

National Atmospheric Deposition Program, 1991, NADP/NTN annual data summary, precipitation chemistry in the United States: Colorado State University, Colorado, Natural Resources Ecology Laboratory, 475 p.

Neely, Jr., B.L., 1986, Arkansas surface-water resources, *in* National Water Summary 1985--Hydrologic Events and Surface-Water Resources: U.S. Geological Survey Water-Supply Paper 2300, p. 151-156.

_____ 1987, Magnitude and frequency of floods in Arkansas: U.S. Geological Survey Water-Resources Investigations Report 86-4335, 51 p.

Nuelle, L.M., 1987, Distribution of radionuclides in Missouri geologic terranes: A summary of available data and the need for more data, *in* Marikos, M.A., and Hansman, R.H., Geologic causes of natural radionuclide anomalies: Rolla, Missouri Division of Geology and Land Survey Special Publication 4, p. 75-90.

Oetking, Philip, Feray, D.E., and Renfro, H.B., 1966, Geological highway map of the mid-continent region: American Association of Petroleum Geologists, map no. 1, 1 sheet, scale 1:1,875,000.

Offield, T.W., and Pohn, H.A., 1979, Geology of the Decaturville impact structure, Missouri: U.S. Geological Survey Professional Paper 1042, 48 p.

Ogden, A.E., 1980, Hydrogeologic and geochemical investigation of the Boone--St. Joe limestone aquifer in Benton County, Arkansas: Arkansas Water Resources Research Center Publication 68, 133 p.

Parkhurst, D.L., 1987, Chemical analyses of water samples from the Picher mining area, northeast Oklahoma and southeast Kansas: U.S. Geological Survey Open-File Report 87-453, 43 p.

Persinger, I.D., 1977, General soil map of Missouri: U.S. Soil Conservation Service, 1 sheet, scale 1:1,333,300.

Petersen, J.C., 1988, Statistical summary of selected water-quality data (water years 1975 through 1985) for Arkansas rivers and streams: U.S. Geological Survey Water-Resources Investigations Report 88-4112, 189 p.

Petersen, J.C., Green, W.R., and Keith, W.E., 1993, Arkansas stream water quality, *in* National Water Summary 1990-91--Stream Water Quality: U.S. Geological Survey Water-Supply Paper 2400, p. 179-186.

Pflieger, W.L., 1989, Aquatic community classification system for Missouri: Jefferson City, Missouri Department of Conservation Aquatic Series 19, 69 p.

Phillips, W.W., and Harper, M.D., 1977, Soil survey of Benton County, Arkansas: U.S. Soil Conservation Service, 90 p.

Rafferty, Milton, 1980, The Ozarks--Land and Life: Norman, University of Oklahoma Press, 282 p.

Robertson, C.E., and Smith, D.C., 1981, Coal resources and reserves of Missouri: Rolla, Missouri Division of Geology and Land Survey Report of Investigations 66, 49 p.

Rueff, A.W.,1990, Mineral and Energy Resources in Missouri: Rolla, Missouri Division of Geology and Land Survey Fact Sheet 3, 2 sheets, scale 1:2,534,000.

Sandhaus, E.H., and Skelton, John, 1968, Magnitude and frequency of Missouri floods: Rolla, Missouri Division of Geology and Land Survey Water Resources Report 23, 276 p.

Sauer, V.B., 1974, Flood characteristics of Oklahoma streams: U.S. Geological Survey Water-Resources Investigations 52-73, 301 p.

Searight, W.V., 1967, Coal, *in* Mineral and water resources of Missouri: Rolla, Missouri Division of Geology and Land Survey, v. 43, p. 235-242.

Smith, B.J., 1988, Assessment of water quality in non-coal mining areas of Missouri: U.S. Geological Survey Water-Resources Investigations Report 87-4286, 50 p.

Smith, C.R., and Steele, K.F., 1990, Nitrate concentrations of ground water, Benton County, Arkansas: Arkansas Water Resources Research Center Miscellaneous Publication 73, 48 p.

Smith, R.A., and Alexander, R.B., 1983, Evidence for acid-precipitation-induced trends in stream chemistry at hydrologic bench-mark stations: U.S. Geological Survey Circular 910, 12 p.

Snider, L.C., 1915, Geology of a portion of northeastern Oklahoma: Oklahoma Geological Survey Bulletin 24, part 1, 130 p.

Spruill, T.B., 1987, Assessment of water resources in lead-zinc mined areas in Cherokee County, Kansas, and adjacent areas: U.S. Geological Survey Water-Supply Paper 2268, 68 p.

Steele, K.F., 1983, Chemistry of springs of the Ozark Mountains, northwestern Arkansas: Arkansas Water Resources Research Center Publication 98, 48 p.

Steele, K.F., Widmann, R.K., Wickliff, D.S., and Parr, D.L., 1985, The effect of rainstorm events on spring water chemistry in limestone terrane: Association of Ground Water Scientists and Engineers, Southern Regional Ground Water Conference, National Water Well Association, Proceedings, p. 51-65.

Stoner, J.D., 1981, Water type and suitability of Oklahoma surface waters for public supply and irrigation, part 1: Arkansas River mainstem and Verdigris, Neosho, and Illinois River Basins through 1978: U.S. Geological Survey Water-Resources Investigations 81-33, 295 p.

Sullavan, J.N., 1974, Drainage areas of streams in Arkansas--White River Basin: U.S. Geological Survey Open-File Report, 123 p.

Terry, J.E., Morris, E.E., Petersen, J.C., and Darling, M.E., 1984, Water-quality assessment of the Illinois River Basin, Arkansas: U.S. Geological Survey Water-Resources Investigations Report 83-4092, 263 p.

Thomas, W.O., Jr., and Corley, R.K., 1977, Techniques for estimating flood discharges for Oklahoma streams: U.S. Geological Survey Water-Resources Investigations 77-54, 170 p.

Thompson, T.L., 1991, Paleozoic succession in Missouri--Part 2, Ordovician System: Rolla, Missouri Division of Geology and Land Survey Report of Investigations 70, 282 p.

Tikrity, S.S., 1968, Tectonic genesis of the Ozark uplift: St. Louis, Washington University, unpublished Ph.D. dissertation, 196 p.

U.S. Army Corps of Engineers, 1967, Water resources development in Missouri, *in* Mineral and water resources of Missouri: Rolla, Missouri Division of Geology and Land Survey, v. 43, p. 349-399.

U.S. Department of Commerce, Bureau of Census, 1990, 1990 Census of population and housing summary population and housing characteristics--Arkansas, Kansas, Missouri, Oklahoma.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1990, Climatological data annual summary (by state): Asheville, North Carolina, National Climatic Data Center.

U.S. Environmental Protection Agency, 1988, Maximum contaminant levels (subpart B of 141, National interim primary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, part 141 revised as of July 1, 1988, p. 533.

U.S. Soil Conservation Service, 1982, General soil map of Arkansas: 2 sheets, scale 1:750,000.

_____ 1986, General soil map of Kansas: 2 sheets, scale 1:1,000,000.

Vineyard, J.D., and Feder, G.L., 1974, Springs of Missouri *with sections on* Fauna and flora, by W.L. Pflieger and R.G. Lipscomb: Rolla, Missouri Division of Geology and Land Survey Water Resources Report 29, 212 p., (reprinted 1982).

Walburg, C.H., Novotny, J.F., Jacobs, K.E., Swink, W.D., and Campbell, T.M., 1981, Water quality, macroinvertebrates, and fisheries in tailwaters and related streams--an annotated bibliography: U.S. Department of the Interior for the U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, Technical Report E-81-8.

Ward, L.B., and Rowlett, J.F., 1984, Soil survey of Fulton and Izard Counties, Arkansas: U.S. Soil Conservation Service, 122 p.

Wharton, H.M., Larsen, K.G., Sweeney, P.H., Harrison, Ed, Bradley, Milton, Davis, J.H., Rogers, R.K., Brown, W.J., Paarlberg, N.L., Evans, L.L., Mouat, M.M., and Clendenin, C.W., 1975, Guidebook to the geology and ore deposits of selected mines in the Viburnum Trend, Missouri: Rolla, Missouri Geology and Land Survey Report of Investigations 58, 56 p.

Wise, O.A., and Caplan, W.M., 1979, Silurian and Devonian rocks of northern Arkansas: Arkansas Geological Commission Information Circular 25, 14 p.